Green roofs and walls as a solutions supporting urban green infrastructure

Zielone dachy i roślinne ściany jako rozwiązania wspomagające zieloną infrastrukturę miast

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Contents – Spis treści

Introduction 7

Wprowadzenie 9

Kamil Skoneczny, Małgorzata Małyszko

Formal and legal aspects of implementing green roofs and walls in selected cities in Europe

Formalne i prawne aspekty wdrażania zielonych dachów i żyjących ścian w wybranych miastach Europy. 11

Katarzyna Chrobak, Piotr Kryczka

Green infrastructure in spatial policy of Wrocław. Verification of urban planning standards and indicators of chosen housing estates

Zielona infrastruktura w polityce przestrzennej Wrocławia. Weryfikacja standardów urbanistycznych i wskaźników wybranych osiedli mieszkaniowych 21

Maria Gerber

Green Architecture in Switzerland

Zielona architektura w Szwajcarii 35

Oleksandra Strashok, Olena Kolesnichenko, Petro Lakyda, Artur Likhanov, Volodymyr Vakhrushkin, Iurii Boigot

Intensive green roofs RC “Smart Plaza Polytech” and RC “Royal Tower” (Kyiv): technology, plant assortment and their vitality

Intensywne dachy zielone KM “Smart Plaza Polytech” i KM “Royal Tower” (Kijów): technologia, asortyment roślin i ich żywotność 47

Kamila Pawłowska

Chinese cities extensive and semi-intensive green roofs

Ekstensywne i półintensywne dachy zielone w chińskich miastach 59

Margot Dudkiewicz, Patryk Krupiński, Mateusz Bartkowiak

Space, time and architecture – a new concept of garden development on the roof of the Vivo! shopping mall in Lublin

Przestrzeń, czas i architektura – nowa koncepcja zagospodarowania ogrodu na dachu galerii handlowej Vivo! w Lublinie 71

Izabela Piklikiewicz-Kęsicka
Possibilities of implementing green infrastructure in modern cities through its applications in workplace architecture
Możliwości wdrożenia zielonej infrastruktury we współczesnych miastach poprzez jej aplikacje w architekturze miejsc pracy 81

Paulina Madej, Bartosz Jawecki
The use of packaging waste in the concept of living wall in the public interior
Wykorzystanie odpadów opakowaniowych w koncepcji żywej ściany we wnętrzu publicznym 89

Jacek Burdziński
Multi-storey car park structures as a potential carrier of greenery in cities
Budowle parkingów wielopoziomowych jako potencjalny nośnik zieleni w miastach 101

Summary 113
Streszczenie 115

Introduction

Green roofs and plant walls are an increasingly visible part of the urban landscape. Used on buildings they not infrequently add to their charm by warming up the image and softening raw, simple forms. However, the visual effect does not determine the popularity of green roofs and living facades. Nowadays, when the world is struggling with the negative effects of climate change, greenery introduced to buildings in fast-growing cities is a necessity, not just a fashion or a visual trend that may soon pass away.

The role of green roofs and plant walls in tackling climate change has been proven in research by scientists around the world. Green roofs and living facades are important tools in climate change adaptation programmes and strategies. For this reason, more and more cities are including them in their development plans, while adapting local legislation in favour of green building development.

Green roofs and plant walls being an important element of green infrastructure, are also the answer to the space shortage problems. Greenery is a natural component of the human environment, introduced to buildings its complements those areas where there is no possibility of making a traditional park or garden. At the same time, rapidly developing building technologies allow for more and more bold applications of greenery in the structure of buildings – both small and large scale, outside and inside the building. This is a field of action for architects, landscape architects or botanists. At the same time, it should be noted that the "fashion for green architecture" is causing a faster development in the construction industry, providing materials for green roofs and living walls. The demand for more and more modern and durable materials in turn triggers the development of scientific research in this field. The continuous exchange of experience between experts from many industries, with the participation of scientists, provides an opportunity to improve green roof and facade technologies and their wider use for the benefit of healthy urban living conditions.

It shouldn't be forgotten that there is a constant need for education in the field of green roofs and plant walls, which can be seen at various levels, e.g. in the administrative or service sectors. Despite widespread knowledge of the benefits of green roofs and living facades, in many countries there is still a lack of formal support and effective implementation tools from local authorities or developers. On the other hand, some European cities boast legal provisions and standards that require every new building under construction to have a green roof. The experience of other countries shows that the implementation of changes takes time, but also should be carried out on a multi-faceted basis: at legislative, administrative and social level. The content presented in this monograph touches on all these aspects. It makes us aware that the implementation of green roofs and walls with vegetation as elements of green infrastructure in cities should be carried out with a holistic approach, based on experience from both domestic and foreign implementations, research and developed concepts.

Wprowadzenie

Zielone dachy i roślinne ściany są coraz bardziej widocznym elementem krajobrazu miast. Stosowane na budowlach architektonicznych nierzadko dodają im uroku, ocieplając wizerunek i zmiękczając surowe, proste formy. O upowszechnieniu się zielonych dachów i elewacji nie decyduje jednak efekt wizualny. W dzisiejszym świecie borykającym się z negatywnymi skutkami zmian klimatu zieleń wprowadzana na budynki w szybko rozrastających się miastach jest koniecznością, a nie tylko modą czy wizualnym trendem, które zaraz mogą przeminąć.

Rola zielonych dachów i roślinnych ścian w niwelowaniu skutków zmian klimatycznych została udowodniona w badaniach przez naukowców na całym świecie. Zielone dachy i fasady są istotnymi narzędziami w programach i strategiach adaptacyjnych do zmian klimatycznych. Z tego powodu coraz więcej miast uwzględnia je w planach rozwoju, przy jednoczesnym dostosowywaniu lokalnych przepisów prawnych na korzyść rozwoju zieleni na budynkach.

Będące ważnym elementem zielonej infrastruktury zielone dachy i roślinne ściany są w strukturze miasta także odpowiedzią na problemy z deficytem powierzchni. Zieleń jest naturalnym składnikiem otoczenia człowieka, wprowadzana na budynki uzupełnia te obszary, gdzie nie ma możliwości wykonania tradycyjnego parku czy ogrodu. Przy tym wszystkim szybko rozwijające się technologie budowlane pozwalają na coraz śmielsze aplikacje zieleni w strukturę budowli – zarówno w małej, jak i dużej skali, na zewnątrz i wewnątrz budynku. Jest to pole do popisu dla architektów, architektów krajobrazu czy botaników. Należy jednocześnie zauważyć, że „moda na zieloną architekturę" powoduje szybszy rozwój w branży budowlanej, dostarczającej materiały na konstrukcje zielonych dachów i żyjących ścian. Zapotrzebowanie na nowocześniejsze i trwalsze materiały uruchamia z kolei rozwój badań naukowych na tym polu. Ciągła wymiana doświadczeń fachowców wielu branż, przy udziale naukowców, daje możliwość udoskonalania technologii zielonych dachów i fasad oraz szersze ich stosowanie z korzyścią dla zdrowych warunków życia w mieście.

Nie należy też zapominać, że istnieje potrzeba edukacji w zakresie zielonych dachów i roślinnych ścian, zauważalna na różnych poziomach m.in. w sektorach administracyjnym czy usługowym. W wielu krajach, pomimo powszechnej wiedzy dotyczącej korzyści z zielonych dachów i roślinnych ścian, wciąż brak formalnego poparcia i skutecznych narzędzi realizacji ze strony lokalnych władz czy firm deweloperskich. Z drugiej strony niektóre miasta europejskie mogą poszczycić się zapisami prawnymi i standardami, według których każdy nowo powstający budynek musi mieć zielony dach. Doświadczenia innych krajów pokazują, że wdrażanie zmian wymaga nie tylko czasu, ale też powinno być wprowadzane wielotorowo: na poziomie legislacyjnym, administracyjnym oraz społecznym. Treści prezentowane w monografii dotykają tych wszystkich płaszczyzn, uświadamiając nas, że wykonanie zielonych dachów i ścian z roślinnością jako elementów zielonej infrastruktury w miastach powinno być realizowane z uwzględnieniem podejścia holistycznego, na podstawie doświadczeń zarówno z krajowych, jak i zagranicznych realizacji, badań i opracowanych koncepcji.

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Formal and legal aspects of implementing green roofs and walls in selected cities in Europe

Formalne i prawne aspekty wdrażania zielonych dachów i żyjących ścian w wybranych miastach Europy

Abstract

In recent years, in Poland, as in many European countries, the trend of sustainable building is growing as a result of an increase in public awareness of environmental protection. Green roofs and walls are often mentioned as one of the elements that, due to many reasons, can positively contribute to changing the environment in cities. This article describes formal and legal aspects, including local regulations in selected cities in Europe. In addition, practical aspects related to the implementation of green roofs and walls were given, treating them as an economic investment.

Streszczenie

W ostatnich latach w Polsce, podobnie jak w wielu krajach Europy, rozwija się trend budownictwa zrównoważonego w wyniku wzrostu świadomości społeczeństwa w zakresie ochrony środowiska. Dachy zielone często wymieniane są jako jeden z elementów, które poza powodami natury estetycznej mogą w pozytywny sposób przyczynić się do zmiany stanu środowiska w miastach. W niniejszym artykule opisano aspekty formalno-prawne, wraz z uwzględnieniem przepisów lokalnych w wybranych miastach w Polsce. Ponadto podano praktyczne aspekty związane z wdrażaniem zielonych dachów, traktując je jako inwestycję gospodarczą.

Key words: green roofs, green walls, city policy
Słowa kluczowe: zielone dachy, zielone ściany, polityka miast

1. Introduction

On Earth, in 2008, more than 50% of the population lived in cities. Studies shows that this trend is maintained and by 2050 more than 70% of the world's population will live in cities (Beatley 2012). From that, it can be concluded that the role of cities in the world will continue to grow. And thus, the action taken by the authorities will become increasingly important from the perspective, not only from the local, but global too.

Progressive development of cities is one of the elements determining an increase in the density of buildings. This involved with reducing green areas that are important for urban architecture. For this reason, the regulations of many European cities can be found (Green roof... 2019; Plan adaptacji... 2019; Praca zbiorowa pod kierownictwem Kurzawy J. 2014) regarding the protection of trees, parks and introducing green roofs and walls into the city landscape. These activities are included in the idea of the Green City, which is part of a wider pro-ecological approach, sustainable development (Hulicka 2015). The functioning of the green city is; reducing noise, using and producing organic food, owning a sewage treatment plant, applying renewable energy, implementing the idea of sustainable transport, sorting garbage, investing in green construction, reducing air pollution, and caring for and designing new green areas (Hulicka 2015). All these activities are aimed at improving the quality of life of residents.

2. Research framework

This article reviews world literature, including magazines, scientific articles, reports and other documents. This article specifically addresses the issue of incentives for the urban environment to set up gardens on buildings, horizontal and vertical. It shows differences and similarities in the approaches of the authorities of several European cities in Europe. The proposed actions are important for the planning and implementation of green infrastructure in cities, as evidenced by similar cities in which similar activities have contributed to increase in green roofs and walls development. For comparison, cities of over 150,000 inhabitants were taken, which included urban greenery programs.

The analysis of available documents made it possible to compare incentive programs for individual cities in relation to climatic conditions in Poland.

The purpose of the dissertation was also to find a range of information about green walls and roofs, their construction, costs and cooperation with other installations, as well as legal requirements necessary for the creation of roof and vertical gardens, which were also presented in the article. In addition to legal requirements, the article also describes formal aspects covering issues related to the implementation of green infrastructure, taking into account construction and environmental requirements, as well as construction and maintenance costs.

3. Gardens of roofs and greenery on walls like green infrastructure in cities – physical requirements

One of the elements of sustainable development in cities is implementation of vegetation on outer building shell. Its essence is the use of energy-saving materials, renewable energy and planning plantings on buildings and in their surroundings. Plantings that are natural components of the eco-system occur in cities in the form of green roofs and green walls. Some of the solutions regarding horizontal partitions can be self-supporting structures or be extensions of existing ones (Malec 2012).

3.1. Green roofs

The term "green roof" does not refer to the color of roofing, but to its ecological properties and the use of greenery in the form of vegetation on the entire roof surface or on a selected part of it. More precise is German term "dachbegruenung" translates as: "greening roofs" which implies implicitly planting the roof with plants (Kania et al. 2013). According to the (Kożuchowski and Kożuchowska 2009) "green roof" mean place on a building constructions that recreate natural ground conditions, allow permanent creation of biologically active areas (Kożuchowski and Kożuchowska 2009). The green roof is assumed to be an open, vegetated surface separated from the ground by a building or other engineering structure. It can be used under the ground surface, on its level or above it.

3.1.1. Classifications of green roofs

The above definitions can be related to various parts of buildings. Later in the article, the concept of the green roof will be narrowed down to the ceiling, but many statements are also true for other engineering structures like terraces.

The green roof is not always the flat one (slope up to 10°), we can distinguish other types due to the varying degree of inclination like sloping (10–25°) and pitched (above 25°). Green roofs with an angle of inclination higher than 45° are not often used. Oblique and steep surfaces require a special type of greening systems (Fig. 1).

As in traditional roofing systems there are non-insulated green roofs, i.e. those that do not have a thermal insulation layer and insulated roofs witch have that layer. Due to the location of waterproofing layers in relation to thermal insulation, insulated roofs can be divided into: standard and inverted. In the first case, the waterproofing layer (roof membrane) is higher than the thermal insulation layer. The introduction of styrofoam insulation resistant to permanent moisture indicate construction of inverted roof (Fig. 2) with the waterproofing layer placed lower than the thermal insulation layer. Roofs of this type are often used because of better protection of the waterproofing layer, its service life is extended and it protects against temperature changes. Rainwater runoff takes place on two levels: the main water mass flow to the drainage system over the insulation, the remaining amount that permeates the heat, is drained on the surface of the moisture insulation (Kania et al. 2013).

Due to the type of greenery used, we can distinguish many types of green roofs dedicated to specific applications, as light, economic, natural, retention, biodiversity, landscape or garden on roof. To each type there are dedicated types of vegetation, substrates and drainage boards. Thickness (without insulation layer) varies from 5 cm to over 1 m, weight changes from 50 kg/m^2 to 1300 kg/m^2 (Technical Brochure… 2019). Therefore, there can be specified another classification connected to subtract thickness witch in significant way affects the vegetation that can be used. Extensive green roofs with vegetation with a shallow root system and low maintenance requirements (substrate thickness from 2 to 15 cm, mass up to 170 kg/m^2). Semi-extensive green roof have 20–30 cm of substrate, so there is a possibility to adapt more types of greenery. Very often it is accessible for pedestrians. Intensive green roofs are often used for most of the year. The desire to increase visual efficiency by making it the garden similar, requires the use of higher vegetation – bush-

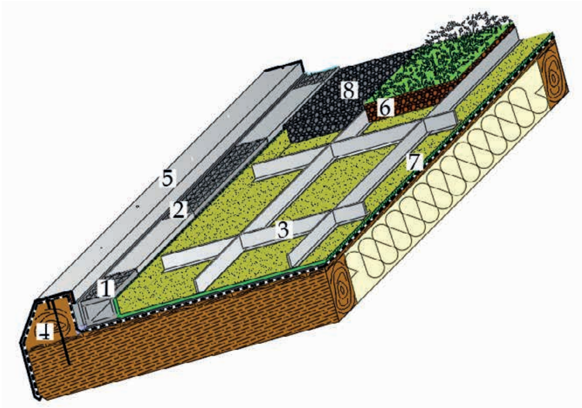

Fig. 1. Anti-slip system for pitched green roofs: 1. Drainage channel, 2. Anti-Slip Safety Shoe, 3. Anti-Slip System, 4. Mechanical attachment for structural kerb, 5. Cover, 6. Substrate, 7. Structured Storage Fleece, 8. Pebble border (Source: own study based on Dachy… 2019)

Ryc. 1. System zapobiegający przed osunięciem dla dachu skośnego: 1. Perforowana rynna odwadniająca z rusztem, 2. Element przenoszący obciążenia nad rynną odwadniającą, 3. System zabezpieczający przed osunięciem, 4. Belka oporowa z mocowaniem, 5. Osłona krawędzi dachu, 6. Substrat, 7. Włóknina chłonno-drenażowa, 8. Opaska żwirowa (Źródło: opracowanie własne na postawie Dachy… 2019)

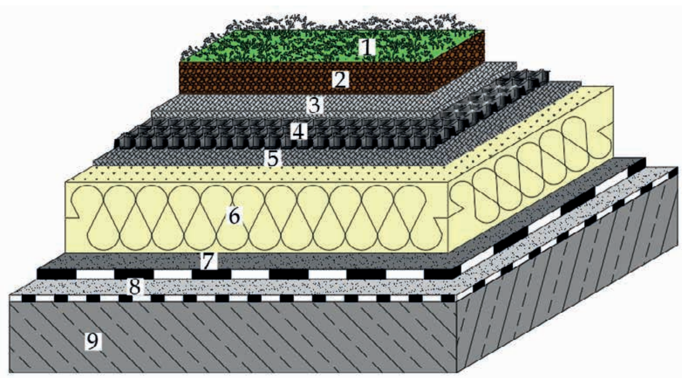

Fig. 2. Layer arrangement on the green roof – inverted construction: 1. Vegetation layer, 2. Substrate, 3. Filter Fleece, 4. Drainage and Storage Board, 5. Trickle Protection Fleece, 6. Thermal insulation, 7. Roof membrane (root-resistant), 8. Protection and separation layer, 9. Concrete deck (Source: own study based on Technical Brochure… 2019)

Ryc. 2. Układ warstw dachu zielonego – dach odwrócony: 1. Warstwa wegetacyjna, 2. Substrat, 3. Geowłóknina filtracyjna, 4. Warstwa drenażowa, 5. Geowłóknina ochronno-dyfuzyjna, 6. Termoizolacja, 7. Hydroizolacja dachu (odporna na przerastanie korzeni), 8. Betonowa płyta konstrukcyjna (Źródło: opracowanie własne na postawie Technical Brochure… 2019)

es, and even trees that need fatigue thicker and heavier layers of substrate (over 30 cm, weight, often exceeding 300 kg/m^2).

Initial cost of implementation green roof in compare to traditional roof is not easy to estimate. It depends of type of the building – existing or new, additional bearing capacity of structural elements, localization of the investment and of course type of green roof and vegetation. Cost assembly of waterproofing layer in traditional flat roof is 20–25 EUR/m^2. The green roof requires additional reinforcement of the structure or other system with higher bearing capacity. Also waterproofing is more expensive due to necessity to implement root resistance layer. Additional costs are drainage and substrate layers with vegetation. Total cost for extensive green roof starts from 40 EUR/m^2. Usually, the annual cost of living is 1–5% of the initial cost depending on the vegetation used. There must be mentioned that the green roof is more durable due to less impact of external conditions, including daily and yearly temperature amplitudes and less solar radiation falling on the waterproofing. In 60 years period time the traditional roofing system requires renovation of the covering every 10–15 years in the form of lawyers or even entire waterproofing replacement what has a significant impact on total cost of this solution (Kożuchowski and Kożuchowska 2009; Luckett 2009).

3.2. Green walls

The vegetation on the walls of buildings can be used in various configurations. The two basic systems are green facades and living walls. Facades covered with vegetation can be made in a way where the organic layer is located directly on the wall and indirectly, where the vegetation is located a short distance from the building wall. In the green facade, the soil substrate is located in one place, it can be planting at the base of the wall, or in a container intended for this purpose.

3.2.1. Construction

The traditional green facade is characterized by a direct coverage of the building facade by a biologically active layer (Pérez et al. 2014), and the soil substrate is located at the foot of the wall (Wesołowska and Laska 2019). This type of solution does not require additional elements supporting the structure, but appropriate vegetation. For this purpose, climbing plants that have the ability to stick to the wall are used. The most resistant to their interference are partitions made of clinker bricks. Plants used for making green walls in Polish conditions have been highlighted in the article (Wesołowska and Laska 2019).

The intermediate green facade requires the use of special elements supporting vegetation, steel cables or meshes, which must be attached to the partition. This method interferes, albeit slightly, with the building structure.

A favorable aspect for a green facade is the lack of soil requirements. Only a small amount is enough for the vegetation to survive and climb upwards. However, in the case of the impact of vegetation on the building, as Trzaskowska writes in her article (Trzaskowska 2010), they have a positive effect on foundations, drawing water from their surroundings when they are planted at its foot.

Living walls have much more demanding requirements than green facades. Their constructions are made of materials intended for this purpose. Based on the construction, vertical gardens made modularly using trays, special dishes, boxes or bags and panel gardens can be distinguished (Cuce 2017). These constructions are characterized by even distribution of vegetation over the entire surface of the partition. The most popular solution is to place plants in the soil, it can be replaced with geotextile (Besir and Cuce 2018). In addition, due to the risk of moisture in the vertical partition, is used a solution in which the vegetation is in a felt substrate insulated from the wall with PVC panels (Malec 2012). All of the living wall solutions require an irrigation system (Besir and Cuce 2018). Small gardens can be irrigated manually, but for large areas this is problematic. Then apply an irrigation system that provides plants also fertilizers.

Particular attention should be given to the weight of plants and structural elements. The green facade will be the lightest solution for a building wall. Whereas the most interfering and stressing structure of the object, due to the necessity of anchoring and the total weight itself, will be the living wall.

There are many companies on the European service market that provide wall services. Sources (Perini et al. 2011; Wesołowska and Laska 2019; Perini et al. 2013) indicate that the cost of a green wall can vary significantly. The more complex the design of a vertical garden, the higher the price per m^2. The least cost-intensive solution is the green facade, which depending on the solution costs 30–75 EUR/m^2. However, in the case of its implementation, where the soil substrate is in special boxes, the price may increase up to 800 EUR/m^2. The price of making a living wall can be even higher. Depending on the material used, type of fastening and vegetation used, m^2 of living wall can reach up to 1200 EUR (Perini et al. 2011; Wesołowska and Laska 2019).

4. Cooperation with other systems

In sustainable cities, there is necessary to use dispersed and renewable energy sources. This need is resulting in the appearance of new ways of developing the external space of buildings. Increasingly, solar panels can be seen on roofs and facades. Climate change cause more and more frequent heat waves, which lead to the desire to improve the comfort of being at work, at home by using ventilation and air conditioning systems that regulate the temperature in the rooms. Therefore, it becomes necessary to find space for the location of ventilation and refrigeration units. External walls and roofs are often used due to much lower cost in comparison to the internal spaces. Area of external surfaces is limited and therefore it is necessary to carefully plan the space and adapt it to the needs of building users and society. In some cases, it is possible to decide on the existence of all solutions (Fig. 3), but sometimes it will be necessary to make a selection taking into account local conditions, e.g. the presence of a significant shading from neighboring objects.

As mentioned, each of the living wall solutions, as well as some green roofs requires irrigation system. They can be made automatically via a droplet system. This system can be connected to the plumbing system or use collected rainwater (Fig. 4).

In the case of using plants in multi-family buildings, a positive opinion and consent of all tenants are necessary. However, in the case of buildings covered by conservation, protection, one must obtain the consent of the monument conservator. Very often the lack of awareness of residents and the fear of using vegetation in the building is one of the biggest barrier against their use.

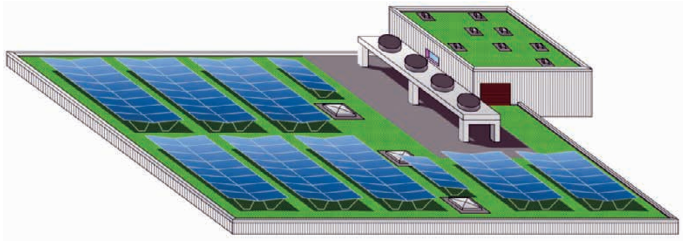

Fig. 3. Example of green roof with solar panels and refrigeration units (Source: own study)

Ryc. 3. Przykład dachu zielonego wraz z panelami solarnymi i agregatami chłodniczymi (Źródło: opracowanie własne)

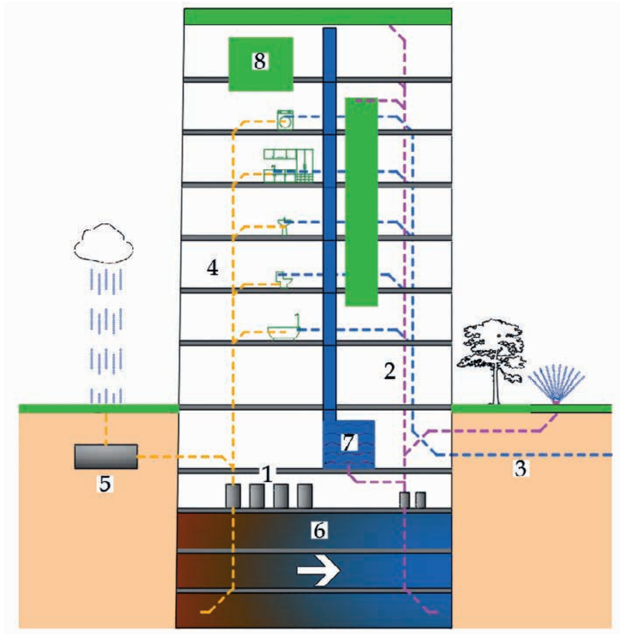

Fig. 4. Project instalation of water in the One Central Park project in Sydney, Australia: 1. Membrane bioreactor for water purification, 2. Recycled water, 3. Potable water, 4. Wastewater, 5. Rainwater collection, 6. Eight-step purification including reverse osmosis and ultraviolet germicidal irradiation, 7. Air cooling towers, 8. Green wall irrigation (Source: own study based on Riley 2017)

Ryc. 4. Projekt instalacji zimnej wody w projekcie One Central Park w Sydney w Australii: 1. Bioreaktor membranowy do oczyszczania wody, 2. Woda z odzysku, 3. Woda zimna, pitna, 4. Ścieki, 5. Zbiornik wody deszczowej, 6. Ośmioetapowe oczyszczanie, w tym odwrócona osmoza i bakteriobójcze promieniowanie ultrafioletowe, 7. Wieże chłodnicze, 8. Nawadnianie zielonych ścian (Źródło: opracowanie własne na podstawie Riley 2017)

5. Politics of the city with planning and realization of green roofs and walls

Europe is called the "old continent", has a large number of ancient objects in its area. Very often they are protected by the conservator of monuments, which means that interference with the construction of external partitions and their reconstruction may be difficult.

One of the solutions that is used to revitalize existing buildings or to hide unsightly historic partitions is to use a green wall.

Large cities are struggling with a shrinking area of vegetation. This results in growing problems with an increased concentration of pollutants in the environment and a lack of places to rest. These are just a few of the many factors that green walls and roofs can help offset.

Many European cities have introduced or are introducing amenities for residents, including tax breaks and subsidies to promote vertical and rooftop gardens. The article covers only a few of the many metropolises using promotional measures of this type of solutions.

5.1. Cracow, Poland

One of the largest Polish cities is Krakow, which is also the capital of the Lesser Poland Voivodeship. The continuous growth of cities, the pursuit of ever greater comfort of living lead to an increasing amount of air pollution. In order to improve air quality in the Lesser Poland voivodship, an air protection program was introduced, which was approved by the voivodship parliament on January 2017 (RIR. Kraków… 2019).

In the resolution (RIR. Kraków… 2019) activities that have a positive impact on air quality in urban agglomerations have been specified. Krakow has been covered by activities related to the development of urban infrastructure, including the use of green roofs and walls. In particular, ventilation of city areas is to be supported by the use of green walls, not only on buildings but also on small urban buildings, including public transport stops or acoustic screens.

In the civic budget programs in the capital of Lesser Poland, there are also applications for green walls. In the 2018 edition, the most votes were collected by the project "Green smog absorber for each district", based on which walls of vegetation will be made. The city of Krakow allocated over 1.7 million PLN for the implementation of this project (Uchwała NR XV/268/15).

5.2. Wrocław, Poland

The city of Wrocław is located from the southwest of Poland. It is the capital of Lower Silesia with the seat of the province. Wrocław as a city is also developing in accordance with the principle of sustainable development. In connection with this idea, the *Provincial Environmental Protection Program for the Lower Silesian Voivodship* was created (Praca zbiorowa pod kierownictwem Kurzawy 2014). One of the objectives set out in the above program is to increase green areas while maintaining existing areas. This provision covers the expansion and creation of new green walls and roofs throughout the city through incentives to accelerate their development.

The authorities of the city of Wrocław in September 2015 issued a resolution (Wspieranie budowy dachów zielonych… 2019), in which they exempt Wrocław residents from real estate tax for residential premises (0.18 EUR/m^2 year). Tax reduction may take place if a green roof is used on the building or if vertical gardens are installed. For vertical gardens, the minimum area required to reduce fees is 15 m^2 on external walls. However, in the case of a green roof, restrictions regarding its area in relation to the number of stories in a residential building have been specified. The situation is similar in relation to a living wall, the percentage of usable area exempt from tax depends on the planting area (Wspieranie budowy dachów zielonych… 2019). The introduced solution to a limited extent contributed to the popularization of green roofs and walls, because in the years 2015–2017 the total number of discounts granted was close. 200 EUR (Wertykalny ogród… 2019). The program will be valid until the end of 2021.

In addition, the authorities of the capital of Lower Silesia, following the trend of "Green City", made a green wall on the building of the municipal office (Photo 1). The project was carried out in 2014, and the wall covered with vegetation covers 100 m^2 of surface.

5.3. Barcelona, Spain

In the 1980s, the Barcelona City Council implemented a program to repair the city walls. It was aimed at improving the visual walls of buildings that were exposed after the destruction of neighboring ones (Bornholdt 2015).

At the beginning, these walls were enriched with additional windows and graphics.

In 2000, the City Landscape Institute of the City Council authorized "Vegitecture", i.e. the use of vegetation on vertical partitions. Today, there are many places in Barcelona with vertical gardens. These are, for example, the facade of the Raval theater, or Jardí Tarradellas (Tarradellas Garden or Green Side-Wall) in the Les Corts district (Bornholdt 2015).

5.4. Basel, Switzerland

An example of support for market mechanisms through a system of incentives for investors is the campaign for greening flat roofs in Basel applied in 1995. Thanks to a special fund on which 4% of revenues from fees for electricity consumption was collected, anyone who decided to green existing or construction new green roof, received a subsidy of around 20 EUR/m^2. As a result, in just 18 months, 120 roofs with an area of 8,000 m^2 were covered in greenery in Basel. Following the success of the first campaign in 2002, an amendment to the local building law was introduced, requiring the greening requirement for all new flat-roofed buildings. In 2005, campaigns providing funding of approximately EUR 35/m^2 of green roof space were re-introduced. As a result, almost two thousand green roofs were hung. In 2009, about a quarter of all flat roofs in Basel are covered with vegetation (Kożuchowski and Kożuchowska 2009).

5.5. Hamburg, Germany

Hamburg since April 2014 has its own strategy to stimulate the construction of green roofs in the city, implementing the idea of the "green smart city". The goal is to plant over 100 ha of roof space in an urban area. The program is dedicated to both new and existing facilities and applies to both private and commercial investors. The city finances up to 60% of the green roof construction costs by offering 35–58 EUR/m^2. Because green roofs largely retain rainwater, in addition, the owner of a building with a green roof can save 50% on rainwater charges. In the absence of a connection to the sewage system, fees for rainwater can be completely reduced. In order to participate in the program, a solution with an area of more than 20 m^2 and a substrate with a thickness of more than 12 cm for new buildings and more than 8 cm for existing ones should be used. The maximum grant amount is 50,000 EUR. An additional goal of this strategy is to incorporate the provisions on green roofs into legal regulations related to construction, water management and spatial planning and green areas (Strategia zielonych dachów… 2019; Banach 2016; Rozporządzenie Ministra Infrastruktury… 2002).

Photo 1. A green wall on the building of the city hall in Wrocław (Author's collection)

Fot. 1. Zielona ściana na budynku Urzędu Miejskiego we Wrocławiu (zbiory autorów)

6. Conclusions

The use of building surfaces is a great possibility to the greening of urban areas. Both residential, industrial, post-industrial and office buildings, existing and newly created ones have great potential that could be used for planting vegetation. By using these solutions, there is possible increase the amount of urban greenery by up to two times (Banach 2016). To this end, many European cities are encouraging, through subsidy projects, tax breaks, to establish vertical gardens and roofs.

In many European countries, the requirements are set for ensuring natural vegetation on building plots. In Poland, the area of the biologically active area must constitute at least 25% of the area of the construction plot intended for multi-family housing, education and upbringing buildings (unless the local spatial development plan provides otherwise). When calculating the surface of the biologically active area, 50% of the terraces and flat roofs arranged as permanent lawns or flower beds on vegetated grounds, with an area of not less than 10 m^2, are included (Rozporządzenie Ministra Infrastruktury... 2002). The use of green roofs in this type of facilities allows for increasing the share of the building's area relative to the area of the construction plot, which is a benefit for investors by the possibility of increasing the usable area of the facilities.

It is worth paying attention to the fact that there is no mention in foreign literature about the activities of greening urban areas in Poland. This may be evidence of few or insufficient actions towards the use of vegetation on roofs and walls. The main difference between the programs implementing green infrastructure in Wrocław and Krakow, and the examples from other cities were the amount of subsidy, as well as the intensity and scope of the social campaign promoting the issue.

The reduction of fees for reducing the amount of rainwater discharged are used is another common way of getting investors to use green walls and roofs. Additional storage of rainwater allows for providing a source of supply for irrigation systems that allow the use of vegetation with greater soil requirements or the survival of vegetation during rainless periods.

The examples analyzed showed that the implementation of greenery within buildings is most effective when subsidies cover part or all of the investment costs, which minimizes the difference in the investment price relative to traditional solutions.

The authors suggest that in order to implement green walls and roofs, it is necessary to increase public knowledge about the possibilities of using this type of solutions. A best way seems to be the presentation of examples of solutions in public utilities and conducting campaigns and social programs related to this topic. The formulation of the strategy for implementing green walls and roofs should translate into the introduction of requirements into local spatial development plans, including flood management aspects, access to urban greenery, reduction of noise intensity, etc. The introduction of subsidies ensuring the reimbursement of part of the costs of applying the preferred solutions by local authorities may translate to increase investor involvement in achieving their goals.

A consistent local policy regarding the greening of urban areas will lead to a transformation in their character. Changing the ratio of biologically active areas to paved surfaces is a necessary element for the idea of a green city. The use of green roofs and walls of buildings is part of a sustainable development policy that works in favor of improving the quality of life of residents.

References

Banach M., 2016. Prośrodowiskowe rozwiązania w architekturze – wybrane aspekty. Zeszyty Naukowe. Inżynieria Środowiska, Uniwersytet Zielonogórski (44).

Beatley T., 2012. Green Cities of Europe: Global Lessons on Green Urbanism. Island Press; https://books.google.pl/books?hl=pl&lr=&id=XrsvOoq41psC&oi=fnd&pg=PR2&dq=green+city&ots=wn6Si5HG9n&sig=Uf3o6mLbubiHrTA4_h8GSQIoCfU&redir_esc=y#v=onepage&q=greencity&f=false [22.08.2019]

Besir A.B., Cuce E., 2018. Green roofs and facades: A comprehensive review. Renew Sustain Energy Rev. 82, 915–939. doi: 10.1016/j.rser.2017.09.106

Bornholdt H., 2015. Green Roof Strategy for Hamburg. Hambg Minist Environ Energy. https://www.bfn.de/fileadmin/BfN/klimawandel/Dokumente/ECBCC2015/2015–11–18/

Session4/Bornholdt_-_Green_roof_strategy_Hamburg.pdf.
Cuce E., 2017.Thermal regulation impact of green walls: An experimental and numerical investigation. Appl Energy (194), 247–254. doi: 10.1016/j.apenergy.2016.09.079
DACHY – pokrycia dachowe, okna dachowe, dachy, membrany, blachodachówka, dachówka cementowa, dachówka ceramiczna, branża dachowa i dekarska, akcesoria dachowe, poddasza. http://klubdachy.pl/przeglad/zielony-dach-na-stromych-polaciach/ [1.10.2019]
Green roof strategy Hamburg. www.hamburg.de/gruendach [22.08. 2019]
Hulicka A., 2015. Miasto zielone – miasto zrównoważone. Sposoby kształtowania miejskich terenów zieleni w nawiązaniu do idei Green City. Prace Geograficzne (141), 73–85.
Kania A., Mioduszewska M., Płonka P., Rabińska J.A., Skarżyński D., Walter E., Weber-Siwirska M., 2013. Zasady projektowania i wykonywania zielonych dachów i żyjących ścian. Poradnik dla gmin. Stowarzyszenie Gmin Polska Sieć "Energie Cités", Kraków.
Kożuchowski P., Kożuchowska E., 2009. Dach zielony – skuteczna metoda zabezpieczania pokryć hydroizolacyjnych. Inżynier Budownictwa (5), 86–90.
Luckett K., 2009. Green Roof Construction and Maintenance. Mc Graw Hill's Greensource.
Malec T., 2012. Ogrody wertykalne w przestrzeni polskich miast. Vertical Gardens in the Urban Space of Polish Cities. Czasopismo Techniczne. Architektura, R. (109), z. 6-A, 299–305.
Pérez G., Coma J., Martorell I., Cabeza L.F., 2014. Vertical Greenery Systems (VGS) for energy saving in buildings: A review. Renew Sustain Energy Rev. (39), 139–165. doi: 10.1016/j.rser.2014.07.055
Perini K., Ottelé M., Haas E.M., Raiteri R., 2011. Greening the building envelope, facade greening and living wall systems. Open J. Ecol., 01(01), 1–8. doi: 10.4236/oje.2011.11001
Perini K., Ottelé M., Haas E.M., Raiteri R., 2013. Vertical greening systems, a process tree for green façades and living walls. Urban Ecosyst., 16(2), 265–277. doi: 10.1007/s11252–012–0262–3
Plan adaptacji miasta Krakowa do zmian klimatu do roku 2030. Wydział gospodarki komunalnej, Kraków 2019.
Praca zbiorowa pod kierownictwem Kurzawy J., 2014. Wojewódzki program ochrony środowiska województwa dolnośląskiego na lata 2014–2017 z perspektywą do roku 2021, Wrocław.
RIR. Kraków Będzie Mieć Zielone Ściany Antysmogowe. http://www.rynekinstalacyjny.pl/aktualnosc/id9614,krakow-bedzie-miec-zielone-sciany-antysmogowe [30.08.2019].
Riley B., 2017. The state of the art of living walls: Lessons learned. Build Environ, 114, 219–232. doi: 10.1016/j.buildenv.2016.12.016
Rozporządzenie Ministra Infrastruktury z dnia 12 kwietnia 2002 r. w sprawie warunków technicznych, jakim powinny odpowiadać budynki i ich usytuowanie (Dz.U. 2002 nr 75 poz. 690 z późn. zm).
Strategia zielonych dachów Hamburg http://zielonainfrastruktura.pl/strategia-zielonych-dachow-miasta-hamburg-wywiad [1.10.2019].
Technical Brochure – Green roof solutions by optigreen. http://www.optigreen.co.uk/specification-support/technical-brochure/ [1.10.2019].
Trzaskowska E., 2010. Wykorzystanie roślin w projektowaniu architektonicznym (pnącza, ogrody wertykalne). Teka Kom. Arch. Urb. Stud. Kraj. – OL PAN. 110–121.
Uchwała NR XV/268/15 RADY MIEJSKIEJ WROCŁAWIA w sprawie zwolnień od podatku od nieruchomości powierzchni użytkowych lokali mieszkalnych w ramach projektu intensyfikacji powstawania terenów zieleni w obrębie Miasta Wrocławia. 2015, (3763).
Uchwała – Program ochrony powietrza dla województwa małopolskiego – Małopolska 2023 – w zdrowej atmosferze, zał. 1, 2013, 1–436.
Vertical Gardens in Barcelona. https://www.shbarcelona.com/blog/en/vertical-gardens/ [30.09.2019].
Wertykalny ogród Urząd Miasta. http://www.zielonesciany.pl/pl/zielona-sciana-wroclaw-urzad-miasta [30.09.2019].
Wesołowska M., Laska M., 2019. The use of green walls and the impact on air quality and life standard. In E3S Web of Conferences Vol. 116, 00096. EDP Sciences. doi: 10.1051/e3sconf/201910000085
Wspieranie budowy dachów zielonych w miastach – pionierskie działania we Wrocławiu. http://zielonainfrastruktura.pl/wspieranie-budowy-dachow-zielonych-w-miastach-pionierskie-dzialania-we-wroclawiu/ [30.09.2019].

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Green infrastructure in spatial policy of Wrocław. Verification of urban planning standards and indicators of chosen housing estates

Zielona infrastruktura w polityce przestrzennej Wrocławia. Weryfikacja standardów urbanistycznych i wskaźników wybranych osiedli mieszkaniowych

Abstract

Nowadays, green infrastructure is more commonly used as a response to negative effects of urbanisation. The aim of this elaboration is to systematise the knowledge of green infrastructure in relation to spatial development of Wrocław on the basis of methodical approach divided into five steps: analysis of main trends of development of green infrastructure in different spatial dimensions, verification of spatial policy in the *Study on land use planning of Wrocław*, analysis of regulations implemented in local spatial development plans and the effect of these regulations on development of newly realised housing estates as well as analysis of potential of development of green infrastructure on the chosen housing estates. As a result, the regulations implemented in spatial policy of Wrocław in the context of development of green infrastructure in urban design were evaluated. In addition, the potential of chosen housing estates was estimated with the construction of implementation guidelines of development of green infrastructure system in spatial policy.

Streszczenie

Współcześnie zielona infrastruktura jest coraz częściej wykorzystywana jako narzędzie przeciwdziałające negatywnym skutkom urbanizacji. Celem opracowania jest usystematyzowanie wiedzy z zakresu zielonej infrastruktury w odniesieniu do wrocławskiego systemu planowania przestrzennego na podstawie pięciostopniowego postępowania metodycznego: analiza głównych trendów rozwoju zielonej infrastruktury w różnych skalach przestrzennych, weryfikacja polityki przestrzennej zawartej w *Studium uwarunkowań i kierunków zagospodarowania przestrzennego Wrocławia*, analiza polityki regulacyjnej zawartej w miejscowych planach zagospodarowania przestrzennego, a w efekcie także wyników implementacji zapisów prawa lokalnego przy kształtowaniu współcześnie realizowanych osiedli Wrocławia, jak również analizy potencjału rozwojowego tych osiedli w odniesieniu do rozwoju zielonej

infrastruktury. W rezultacie oceniono zasady wrocławskiej polityki przestrzennej odnoszące się do projektowania urbanistycznego uwzględniającego potrzeby realizacji zielonej infrastruktury. Ponadto określono potencjał analizowanych osiedli z uwzględnieniem niezbędnych sugestii planistycznych możliwych do implementacji w późniejszych opracowaniach urbanistycznych miasta.

Key words: green roofs, green walls, city policy
Słowa kluczowe: zielone dachy, zielone ściany, polityka miast

1. Introduction

While the majority of population in Europe live in cities and areas that are threatened by intensive anthropopressure, shaping of natural system is especially important in the process of mitigation of negative effects of urbanization. Among the benefits of green infrastructure, many authors underline these connected with urban areas i.e. the reduction of *urban heat island*, increase of air humidity (Dawson et al. 2014), furtherance in water management (Foster et al. 2011), improvement of air quality (Sandström 2002) as well as regulation of ecologic conditions (Szulczewska 2018) and providing recreational and integration places for city dwellers (Ahern 2007).

The crucial role in the process of shaping urban green infrastructure has spatial policy on every spatial dimension – from macroscale to local and site scale (Ociepa-Kubicka 2014). Every scale of spatial planning relates to different aspects and elements of green infrastructure and involve various stakeholders (i.a. politicians, municipalities, landscapers, urban planners, architects and developers). This involvement should be also reflected in spatial planning documents on every of these levels, where the selection of proper measures should be related to spatial scale and the specificity of the document.

In the scale of the city, urban planning documents have the essential role in shaping the spatial policy of greenery systems. By defining the urban standards and indicators, plans have a real impact on final realisations of housing estates. In this context, the main aim of this study was to compare the urban planning standards and indicators connected with green infrastructure and natural environment (on the basis of *Study on land use planning of Wrocław* and chosen local spatial development plans) with the standards attained in realised housing estates. On the purpose of this evaluation, four housing estates were chosen: Swojczyce – Olimpia Port, Nowe Żerniki, Stabłowice – Wojanowska and Marszowice Malownicze. For the purpose of detection of connections in larger scale and verification of the holistic approach to spatial policy associated with green infrastructure in Wrocław, all of them are adjoined to the area of dominant greenery system of Wrocław. What is more, chosen housing estates are recent developments, sometimes unfinished, which enabled to predict their further development on the basis of its foregoing development and indicators included in spatial development plans.

2. Materials and methods

2.1. Typology of green infrastructure in different spatial scales

Green infrastructure is differently defined depending on applied approach or scale reference. Pirowski (2014) distinguishes three main groups of references that are the basis for definition groups for green infrastructure:

- the group of network definitions, that are based on an underlined role of shaping functional connections between green areas that are central to conserve biodiversity and to maintain functions of the whole system (the idea of green hubs and corridors);
- the group of hydrological definitions, that emphasize the key role of green infrastructure connected with technical solutions in water collection and retention systems;

- the group of integrated definitions, in which the wide set of functions of green infrastructure is highlighted. In this group green infrastructure is understood as areas covered with greenery and water, but also as structures such as green roofs, walls or single trees.

Szulczewska (2018) distinguishes other two groups – the group of intangible definitions and the group of technical definitions, but as she notes – these groups of definitions are not commonly used.

Alleged definitions relate to the spatial scale of the referenced areas. Szulczewska (2018) in the topology of green infrastructure analyses, singularises the continental scale, the regional scale, the local scale and the site scale. The continental and the regional scales mainly refer to the *network* definition group. The elements of green infrastructure in European scale are defined i.a. in Mubareka et al. (2013) or Liquate et al. (2015) studies. In Europe the relations to continental scale are contained in European Union documents and reports (i.e. *Green infrastructure and territorial cohesion. The concept of green infrastructure and its integration into policies using monitoring systems* (EEA 2011), *Green Infrastructure (GI) – Enhancing Europe's Natural Capital* (European Commission 2013) or *Spatial analysis of green infrastructure in Europe* (EEA 2014). The regional scale refers to the scale of the country, but also to smaller areas i.e. the scale of the voivodeship in Poland. The elements of green infrastructure in this scale were defined i.a. in Benedict and McMahon (2002) study, and later in Landscape Institute Position Statement (2009). In Polish spatial planning documents the elements of green infrastructure at this scale, are included in National Spatial Development Concept and spatial development plans for voivodeships.

The main concern for the authors are the local scale and the site scale. The local scale is connected with the scale of the city. Green infrastructure in this relation contains elements such as: business settings, city parks, urban canals, urban commons, forest parks, continuous waterfront, municipal plazas, lakes, major recreational spaces, rivers and floodplains, brownfield land, community woodlands, (former) mineral extraction sites, agricultural land and landfill (The Landscape Institute 2009). This scale is connected with the group of *integrated* definitions. The rules for shaping green infrastructure associated with urban planning are contained in various handbooks i.e. *Planning for a Healthy Environment – Good Practice Guidance for Green Infrastructure and Biodiversity* (Country Planning Association and The Wildlife Trusts 2012) or *Strategic Green Infrastructure Planning. A Multi-scale Approach* (Firehock, Walker 2015). Szulczewska (2018) made an attempt to systematise these guidelines and according to this systematisation, green infrastructure should be:

- a strategically planned, integrated, continuous and multifunctional network;
- coherent with local environment and landscape;
- planned with the knowledge of local resources and problems (i.e. flood risk);
- accessible for local community;
- implemented with the coordinated strategic planning;
- realised on the basis of strategy and urban planning documents;
- financed continuously to provide a proper maintenance.

In Polish urban planning law elements of green infrastructure in the city scale should be included in study on land use planning – the document that is obligatory for every commune.

The site scale is related to the dimension of housing estate and is mainly connected with water management. Defined like this, it refers to hydrological group of definitions but it is important to note, that green infrastructure in this scale should be understood more widely – also connected with creation of public places for city dwellers. Elements of green infrastructure, that can be distinguished in this scale, are as follows: street trees, verges and hedges, green roofs and walls, pocket parks, urban plazas, town and village greens and commons, local rights of way, pedestrian and cycle routes, cemeteries, burial grounds and churchyards, institutional open spaces, ponds and streams, small woodlands, play areas, local nature reserves, school grounds, sports pitches, swales, ditches, allotments and vacant and derelict land (The Landscape Institute 2009).

The rules for shaping green infrastructure in the site scale associated with hydrological approach are defined as low impact development. It is connected to three main principals: conservation design (i.e. open space preservation, shared driveways or reduced setbacks), infiltration practices (porous pavement, rain gardens, disconnected downspouts) and run-off storage practices (parking lot, street and sidewalk storage, green roofs or depressional storage) (METRO water services and US Army Corps of Engineers 2009). In Polish urban planning law this scale is associated with the dimension of local spatial development plans. The Act of March 27, 2003 on spatial planning and development (2003) also refers to hydrological definitions with the obligatory to define rules of buildings structures and indicators of land-use development i.a. maximum and minimum intensity of development or minimum percentage of biologically active surface in local spatial development plans with also requirement to determine rules of environment, nature and landscape conservation in these documents.

2.2. Methods

Understanding of the term of green infrastructure in local and site dimensions prompted the authors of the study to the verification of urban planning standards and indicators directly related to shaping the greenery system. Initially, a critical evaluation of literature and analysis of spatial policy of Wrocław (in particular, urban planning standards and indicators as well as regulations in the field of protection and management of local natural environment) were carried out. The aim of the study was achieved through a ratio analyses based on the detection of urban indicators within the study areas. At the beginning, land use analyses were prepared on the basis of three principal elements that are related to green infrastructure. First element is connected with the analysis of surface retention divided into pervious surface, impervious surface and semi-pervious surface. Subsequently, the analyses of future spatial development included in local spatial development plans with differentiation of the category of land use were prepared. Additionally, the analyses of chosen elements of spatial composition that enhance the value of environment were developed – especially tree lanes that were only planned or planned and also implemented in the investment phase. The results of this stage were presented as maps that pictured all of the analytical elements discussed above.

Following the developed maps, the indicators related to surface that allows natural retention were calculated within the study boundary. It was also noted, that some parts of the analysed areas are under development or currently are green areas where in the local spatial development plans different category of land use were determined (i.e. housing or services). Therefore, it was important to delimitate the area that is already developed (called as determined area) and the area that will be transformed in the future (called as non-determined area). At the next step ratio analyses of the statistical plot were calculated. The statistical plot was chosen on the area where the housing development was completely finished. The calculated standards and indicators of statistical plot, also based on the standards included in local plans, were the basis for computing the projected development of the estate. Simultaneously, for non-determined area the predicted ratio of surface that allows natural retention was analysed, based on the planned indicators and calculated standards in statistical plot. Finally, the indicators of determined and non-determined area were summed up. Consequently, it contributed to determine a target scenario of spatial development of the whole housing estate. The ratio analyses were also supplemented with an urban inventory in order to verify the regulations of local plans and implemented environmental solutions.

2.3. Green infrastructure in urban planning documents of Wrocław

2.3.1. The Study on land use planning of Wrocław

The Study on land use planning of Wrocław defines the policy of shaping greenery as the "greenery without limits" with the central role of spatial accessibility to diversified forms of greenery for city dwellers. Greenery in this approach should be an element of every urban structure and serve ecological, protective, recreational and aesthetic functions. In the holistic approach, document contains the need of shaping greenery system with the green and blue infrastructure approach. Document also underlines the necessity of increasing the green areas as important to conserve and enhance the biodiversity. This mission is supposed to be accomplished on the basis of the policy in which three main greenery zones are distinguished. The dominant greenery zone, which is defined in the study as different urban unit, and contains areas that are crucial in protection of the environment with biodiversity and green corridors conservation. The next is the cocreation greenery zone that contains green buffers with the isolation function. In the context of analysed housing estates, the most important is the equivalent greenery zone. It includes points, lines and areas associated with greenery. System of these elements should provide proper functioning of ecosystems, enhancement of urban structure, as well as integration of both city structure and city dwellers with greenery. *The Study on land use planning of Wrocław* also defines the indicators of minimum percentage of biologically active surface for 13 distinguished groups of areas, but defines them as proposed and not explicitly mandatory while compiling spatial development plans. Document distinguishes 16 types of areas defined on the basis of the greenery condition in them (5 connected with dominant greenery zone, 8 connected with different types of housing estates, 2 connected with services and 1 with industry).

Swojczyce – Olimpia Port, Nowe Żerniki and the part of Stabłowice housing estates are in the multifamily housing estates zone. This policy includes newly realised estates (within last 20 years) or non-invested areas alongside main roads. *The Study on land use planning* diagnose the necessity of creation of functional connections in them (as avenues or shared driveways) between green infrastructure elements (especially interior yards) and the dominant exterior greenery system. It is especially important while the estates are usually enclosed. *The Study* also underlines the need for providing hydrological and biological functions of greenery because of the high density of development. The other part of Stabłowice and Marszowice Malownicze housing estates are in the single-family housing estates zone policy. This policy is associated with the areas in which main function of greenery is individual recreation with the lack of public greenery and consistent functional structure of green spaces. *The Study* notes the necessity to provide open-access green areas in them (also within allotment gardens) that will be the significant places for local communities.

2.3.2. Local spatial development plans

Spatial policy is defined as totality of coordinated actions of public entities, aimed at changing urban development in accordance to the designated socio-economic goals (Zaborowski 2012). Therefore, it should be noted that spatial policy of polish urban planning system defines strategic guidelines for spatial development. Nevertheless, the local spatial development plan is a consecutive tool for shaping urban space. Thereupon, the regulations of local spatial development plans, that covers the study area, were analysed. Seven resolutions of the City Council of Wrocław from 2003 to 2015 were investigated (Fig. 1). Each of the plan had been enacted before the *Study on land use planning of Wrocław* was legislated in 2018.

It is important to underline, that plans should be consistent with urban planning standards and indicators that are a part of regulations of the study on land use planning. In this case, for the chronological reasons, analysed plans were compiled on the basis of study on land use planning that is no longer operative. Nevertheless, it is worth pointing out that the latest study on land use planning and its solutions should be included in subsequent changes in local plans.

At the first stage, in each of analysed plans the values of urban planning standards and indicators (such as: maximum val-

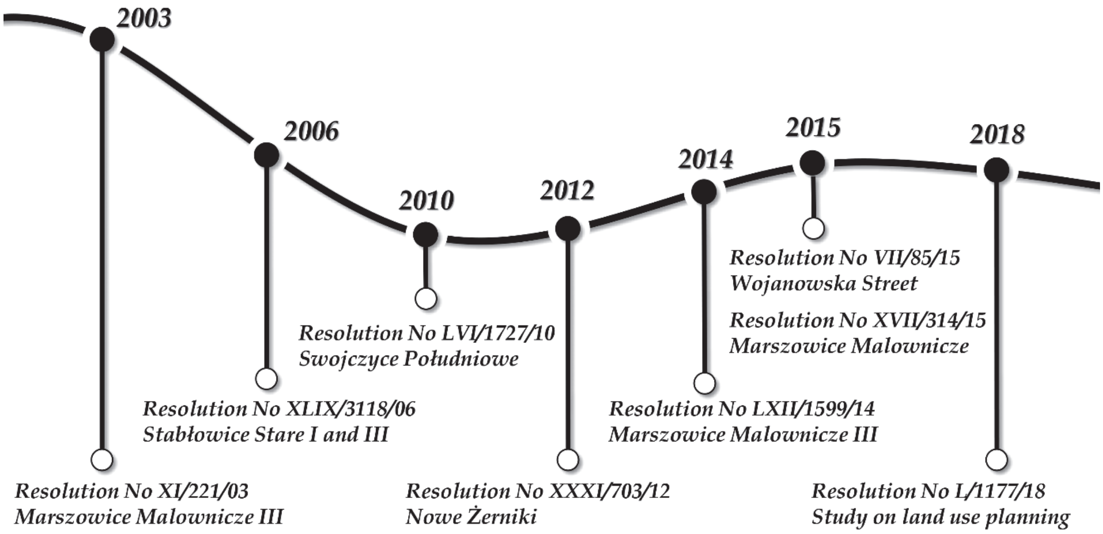

Fig. 1. Timeline of the investigated urban planning documents, Wrocław, Poland (Source: own study)

Ryc. 1. Oś czasu analizowanych dokumentów planistycznych, Wrocław, Polska (Źródło: opracowanie własne)

ue of gross covered area, maximum intensity of development indicator and minimum percentage of biologically active surface) were analysed. These indicators are presented in Table 1. The values differ depending on the category of land use, i.e. single-family housing development, multi-family housing development, greenery and recreational development or greenery with additional services. Albeit, in some local plans, obligatory standards and indicators do not appear (despite its presence in § 39 of the ordinance of the Minister of Infrastructure (2002) on the technical conditions of buildings and its location) or the regulations are not accurate. This lack of proper standards, in particular of principles for shaping the biologically active surface is considered to be very negative trend.

Subsequently, it was considered as important to analyse the qualitatively value of the regulations of the local spatial development plans. The synthetic conclusions of the regulations are listed below:

- land-use development associated with environment involves parks, recreational glades, squares, thematic gardens and open water (as different land-use categories or zones within category (i.e. housing));
- in zones there are sometimes additional regulations i.e. increased area of biologically active surface (up to 80%) or obligation to plant trees in specified part of the area;
- sometimes implement ratio of biologically active zone types (i.e. 65% of natural vegetation surface and 35% of green terraces and roofs);
- define the term *tree lane* and implement obligation to create it alongside roads;
- always implement obligation to create greenery on non-built areas but sometimes without specified regulations (especially in older plans);
- sometimes allow part of biologically active surface (i.e. for housing category) on greenery category that is adjacent to this category;
- define greenery categories as public areas;
- forbid to cover watercourses in specified ratio (i.e. in 20%) and sometimes implement obligation to create biologically zone alongside them;
- implement regulations related to conservation of existing trees;
- regulations in older plans allows clearance of trees but with obligation of compensation;
- older plans implement obligation to collect downcome water on property.

Critical analyses of the regulations of the local spatial development plans formed the basis for the next analytical step.

Table 1. Urban planning standards and indicators in local spatial development plans in relation to different category of land use (Source: own study)

Tabela 1. Wskaźniki urbanistyczne w miejscowych planach zagospodarowania przestrzennego w odniesieniu do różnych kategorii pokrycia terenu (Źródło: opracowanie własne)

Standard or indicator	Value of standard or indicator			
	Marszowice	Stabłowice	Żerniki	Swojczyce
Single-family housing development				
max. gross covered area	30%; 25%	–	no data	–
max. intensity of development indicator	0–1,2; 0–1,0	0,5; 0,6; 0,8	no data	–
min. percentage of biologically active surface	50%	–	30%; 40%	–
multi-family housing development				
max. gross covered area	30%; 25%	b/u	no data	30%, 40% 30%, 50%
max. intensity of development indicator	0–1,2; 0–1,0	0,0–1,0	no data	no data
min. percentage of biologically active surface	50%	30% 40% 50%	30%	25%
Services				
max. gross covered area	40%	22% 35% 38% 40%	no data	50%
max. intensity of development indicator	0–2,5	0,15–0,35 0,5–1,0 0,5–1,2 0,7–1,2	no data	no data
min. percentage of biologically active surface	30%	10% 15% 20%	15%	25%
Greenery				
max. gross covered area	–	–	–	–
max. intensity of development indicator	–	–	–	–
min. percentage of biologically active surface	no data	60% 90%	50%	70%
Recreational development or greenery with services				
max. gross covered area	–	no data	no data	20%
max. intensity of development indicator	–	no data	no data	no data
min. percentage of biologically active surface	–	50% 60%	50%	50%

3. Results

Verification of urban planning standards and indicators on the basis of methodical approach described above was prepared for Marszowice Malownicze, Stabłowice – Wojanowska, Nowe Żerniki and Swojczyce – Olimpia Port housing estates. Results of the surface retention analyses in different categories of land use are presented in the Table 2 and in the Figure 2. The categories of land use are divided into pervious surface (surface water, forest and shrub, lawn on subsoil or track), semi-pervious surface (lawn on underground garage, paving stone that allows infiltration, gravel or crushed stone road as well as aggregated area of the ground under allotment garden and cemetery that has mixed character) and impervious surface (pavement or sidewalk (concrete, stone or bituminous), as well as built-up area). The analyses contain also other categories of land use, which were defined in particular as currently developing areas and areas not matching

Table 2. Results of the surface retention analyses in different category of land use (Source: own study)

Tabela 2. Wyniki analiz przepuszczalności terenu w różnych kategoriach pokrycia terenu (Źródło: opracowanie własne)

Category of land use	Area [ha]			
	Marszowice	Stabłowice	Żerniki	Swojczyce
study area	46,1373	65,8466	34,5228	30,2688
Pervious surface				
surface water	0,9100	0,1525	0,2148	0,1101
forest and shrub	0,0000	1,7190	0,0000	0,0646
lawn on subsoil	26,7118	25,22085	24,3505	12,8538
track (natural pavement or sidewalk)	0,2298	0,3715	0,0175	0,5617
percentage share in study area	60,37%	41,71%	71,21%	44,90%
Semi-pervious surface				
lawn on underground garage	0,0000	0,5645	0,1885	0,1746
paving stone (that allows infiltration)	0,0000	0,0860	0,0000	0,0833
gravel or crushed stone road	0,5912	0,6469	0,1586	0,9149
ground under allotment garden and cemetery (mixed character)	0,0000	12,4551	0,0000	1,3503
percentage share in study area	1,28%	20,89%	1,01%	8,34%
Impervious surface				
pavement or sidewalk (concrete, stone)	9,3662	12,87055	3,2269	5,0624
pavement or sidewalk (bituminous)	0,5689	3,087	1,4631	1,5295
built-up area	5,3163	7,6443	3,0135	6,546
percentage share in study area	33,06%	35,84%	22,31%	43,40%
Analyses of spatial development in local spatial development plans				
zones with environmental restrictions	3,4753	0,2146	0,7406	0,1639
greenery	0,0000	0,3567	4,9939	4,0804
recreation area	0,0000	1,4422	0,0000	0,607
single-family development (with services)	1,4349	12,6190	2,1572	0,0000
multi-family development (with services)	0,5791	3,7307	16,4089	0,8092
services	0,9405	1,6356	0,0000	3,0997
transportation system	0,1428	2,2560	4,4177	0,2391
Other				
other area	2,4431	1,5929	2,0779	1,1922
percentage share in study area	5,30%	2,42%	6,02%	3,94%

other categories. In the non-determined areas, the planned categories of land use were also calculated and crosshatched on the map.

In the case of Marszowice estate, current development status is high (87,26%) and it means that 13% of the area of the estate is possible for further development – as shown in the Figure 3. There is a high proportion, around 41%, of pervious surface covered by bottle green colour. The calculated indicators of statistical plot, based on the standards in local plans, were the basis for computing the projected development of the estate. Almost 60% of the area is estimated to be pervious surface and almost 38% will be impervious surface with 14% of built-up area. Target scenario of spatial development and its indicators is even better than designed in local spatial development plans. These proportions are considered to be appropriate in single-family housing.

In Stabłowice estate current condition shows that pervious surface dominates, but in chosen statistical plot this ratio is equilibrated with impervious surface. 64% of the area is categorized as determined area. Target

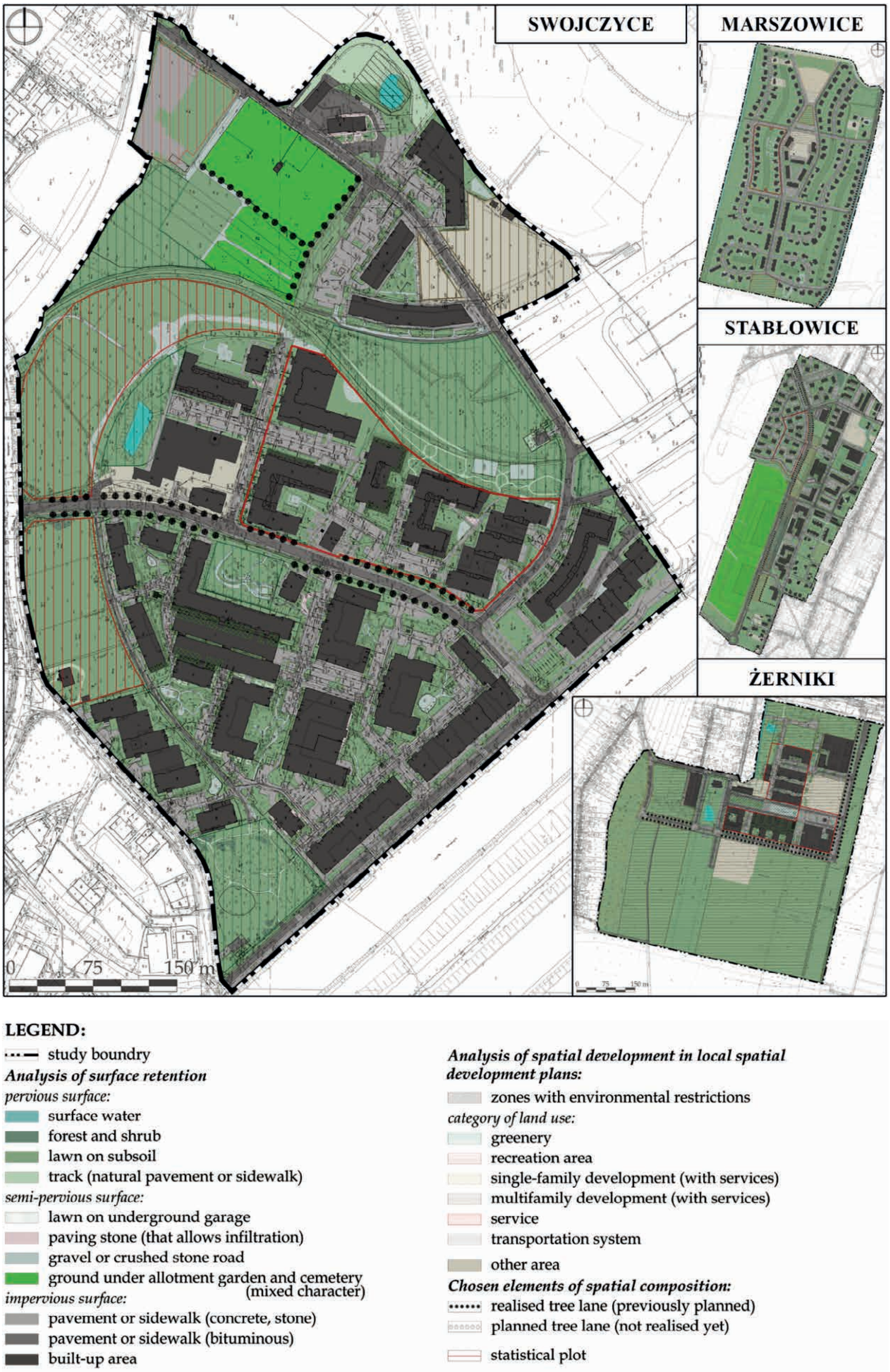

Fig. 2. Spatial analyses (surface retention, spatial development, spatial composition) of chosen housing estates (Source: own study)

Ryc. 2. Analizy przestrzenne (przepuszczalność terenu, rozwój przestrzenny, kompozycja przestrzenna) wybranych osiedli mieszkaniowych (Źródło: opracowanie własne)

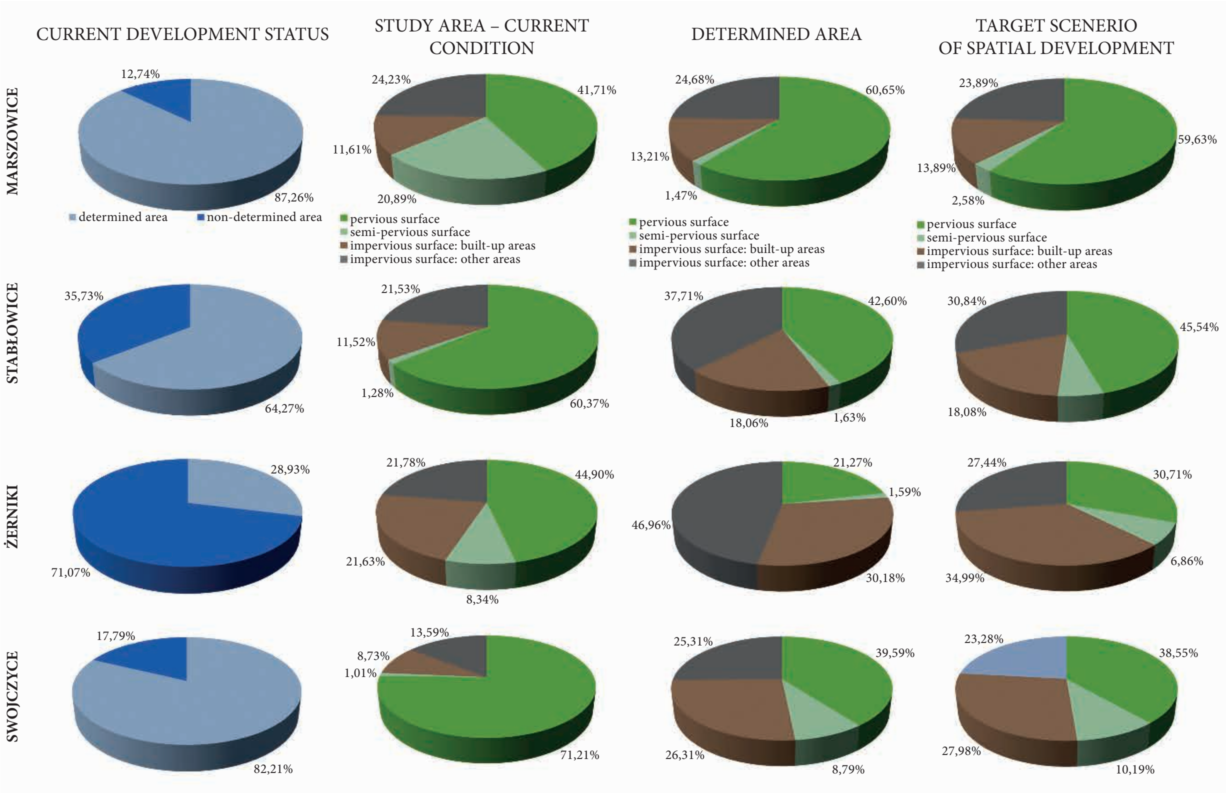

Fig. 3. Results of ratio analyses of chosen housing estates (Source: own study)

Ryc. 3. Wyniki analiz wskaźnikowych wybranych osiedli mieszkaniowych (Źródło: opracowanie własne)

scenario indicates sustainable development in the case of the area of surface natural retention (Fig. 3). A negative trend can be noticed as the lack of some indicators in the local spatial development plan (Table 1).

The analyses are different in the case of Nowe Żerniki estate, where the value of determined area is only 29%. Therefore, the analyses for the statistical plot were especially important. Differences in the level of surface natural retention between Żerniki estate and statistical plot are significant. For example, in the analysed area there is almost 55% of the pervious surface while in statistical plot the value reaches nearly 15%. If development trends would be maintained, the share of built-up area will increase. Furthermore, in this case the indicators from the local plan will be implemented with additional margin and the target standards seem to be sufficient in relation to multifamily housing estate.

The determined area of Swojczyce covers more than 82% of the estate. The future development should be focused on providing services for dwellers in the north part of the urban unit – as shown in the Figure 2. It is important to underline that urban planning standards and indicators included in local spatial development plan are rather low (i.e. 25% of biologically active surface in the multifamily development – Table 1). But the actual realisation of the housing estate has much higher indicators than proposed in the local plan. It should be considered as a positive trend.

The regulations included in local spatial development plans in Polish urban planning system are the most important elements of shaping the target scenario of urbanized space. Therefore, the calculation of urban planning standards and indicators was supplemented with an analysis of implemented solutions in the field of water and green sensitive urban design. Consequently, the urban planning solutions were evaluated in the terms of the regulations of local spatial development plans.

A high proportion of biologically active surface is noted in the area of Maszowice estate. It is important in relation to the local values of the green infrastructure, but not many additional solutions have been found. During site inspection, the hydrophilous plants alongside watercourse as well as pavement that enables water infiltration were observed (Fig. 4, letter A). As shown in the Figure 4 by red cross, these solutions are not the results of the regulations of the local plan. The substantive similitudes can also be seen in the case of Stabłowice estate. Nevertheless, existence of the multi-family residential buildings and underground garage created other possibilities for important urban solutions, i.e. lawns on subsoil inside the yard above the garage (Fig. 4, letter B) or fragments of green walls on the back decks. These are also a non-plan implementations, realised at the stage of investment process.

Much more important urban solutions were introduced in Żerniki and Swojczyce estates. In the case of the first one there are implemented: retention basins, hydrophilous plants (Fig. 4, letter C), green walls (Fig. 4, letter C), green roofs (Fig. 4, letter E), diversified lay of the land and the only one plan implementation – open water (Fig. 4, letter D). The highest intensity of very important urban solutions was noted in Swojczyce estate, where the green walls as well as façade gardens (Fig. 4, letters G and I), retention basins and bioswales (Fig. 4, letter F) and open water (Fig. 4, letter H) were implemented. None of the discussed solutions are the regulations of the local spatial development plans.

4. Discussion

The conducted analyses of urban planning policy in Wrocław in relation to green infrastructure development are connected with research on issues of environmental aspects in spatial policy. In recent studies, also described in literature review, the aspect of sustainable development is confirmed to be especially important in the process of urban development. The analyses show the dichotomy between urban planning documents and actual realisations of housing estates. While in the realisation stage the green infrastructure connected with hydrological solutions is implemented in projects, the spatial development plans contain only basic spatial standards and indicators and do not implement important elements of green infrastructure.

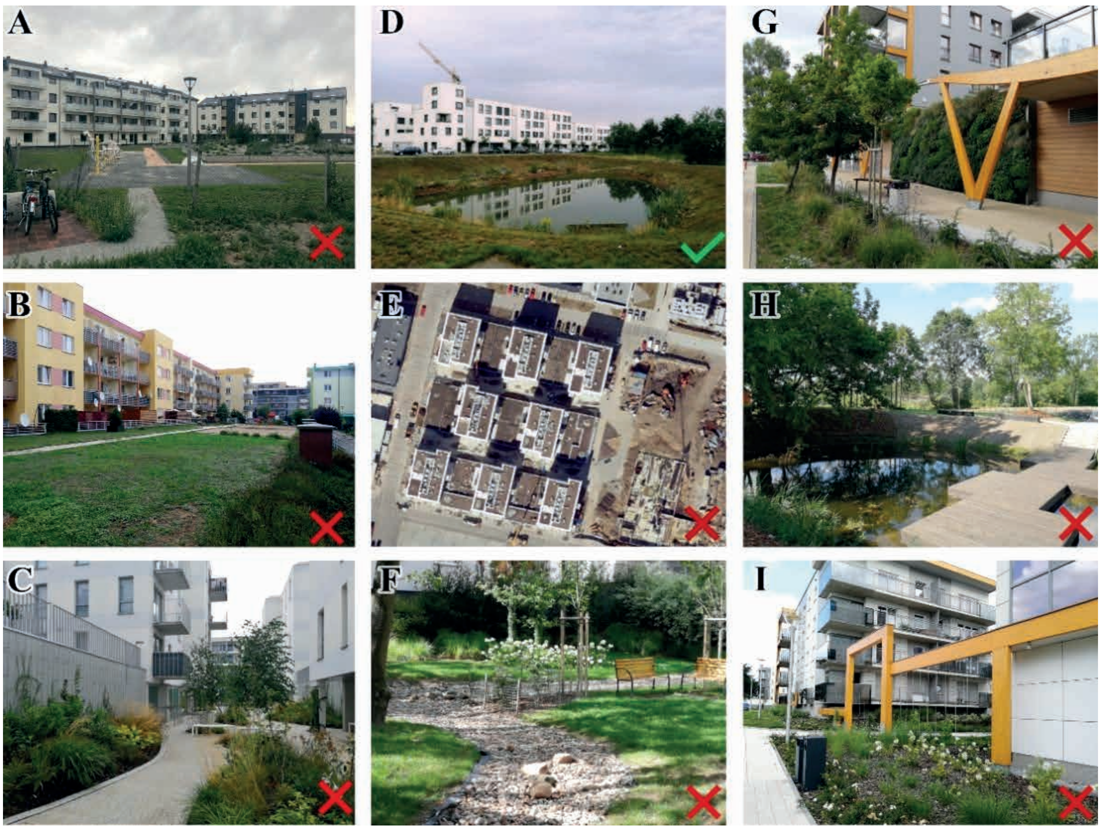

Fig. 4. Chosen solutions of water and green sensitive urban design (Source: own study)

Ryc. 4. Wybrane rozwiązania projektowania urbanistycznego związane z wodą i zielenią (Źródło: opracowanie własne)

That observation is the beginning of further discussion about changes that should be made in an approach to compilation of spatial development plans in relation to environment conservation. The basic indicators and standards, that are required on the basis of *The Act of March 27, 2003 on spatial planning and development* (2003), do not provide the proper development of green infrastructure connected with retention systems, especially while the Europe is facing climate changes. Urban planners that compose spatial development plans, should consider implementation of elements of green infrastructure, that will quantitatively and qualitatively improve environmental standards of housing estates. These rules for shaping the greenery in residential areas should be associated with local drainage conditions and water storage capability.

The ratio analyses and the site inspection made it possible to assess the quality of regulations of chosen local plans prepared by the municipal office in Wrocław. The developed results shown in the tables and diagrams should be considered as important in shaping the guidelines for the spatial policy of metropolitan city. However, it should also be noted that the results may vary depending on area of the study. Taking cognisance of the need to analyse urban space in the discussed subject field may increasingly contribute the quality of green infrastructure. As a result, it may also enhance the potential of the local spatial development plans, which does not implement regulations connected with the modern trends of water and green sensitive urban design.

The actual changes can be made only with the holistic approach to green infrastructure system on every spatial scale. The crucial role in this area have the spatial policy, which should highlight the main directions of green development that should be mandatory while compiling urban planning documents, in which the level of execution of standards and indicators should also be enhanced.

5. Conclusions

The spatial policy of Wrocław, included in urban planning documents, presents the diversified level of advancement of regulations connected with environment. *Study on land use planning* specifies the necessity of development of integrated system of greenery in the whole city (defined as green infrastructure), what is coherent with the newest European trends, but standards and indicators are defined as proposed and are not explicitly mandatory while compiling spatial development plans. The analysed spatial development plans do not present holistic approach in the field of integration of dominant greenery zone with greenery in housing estates. Implementation of zones with additional environmental regulations in spatial development plans is considered as a positive trend, but sometimes the nonfeasance on realisation stage can be noticed – despite the mandatory regulations in spatial development plans the obligation of greenery development is not executed and fulfilled. Nevertheless, conducted analyses show positive trends associated with urban development, while standards of realised housing estates have higher share of pervious surface than obligatory in plans. The positive trend of including hydrological conditions by architects can also be noticed, while spatial development plans have rather laconic regulations in this area. Conducted analyses show that the spatial development plans should be updated to be coherent with the newest directions of spatial policy of Wrocław and the newest trends of creating green infrastructure in housing estates. Taking these actions by municipalities should provide the proper development of green infrastructure in Wrocław and minimalization of negative effects of intensive urbanisation on the area of the city and also suburban, rural areas.

Realized analyses show that the urban planning standards and indicators included in local spatial development plans should be more stringent. The need to specify additional indicators or guidelines that will improve the ecological efficiency of planned estates should also be noticed. The crucial urban solutions (in connection with the green and water sensitive urban design trend) as a part of the projects at the implementation stage are implemented by architects and civil engineers. Swojczyce and Żerniki estates are good examples in regard to shaping the urban space with environmentally friendly solutions, such as: retention basins and bioswales, green walls, façade gardens and green roofs, but mostly it was not included in the local spatial development plans. Therefore, in relation to generally applicable law in Poland, environmental regulations in local plans should be evaluated and consequently modified in the vein of the need to adapt to climate change. The very first positive step was a legislation of *Study on land use planning of Wrocław* in 2018.

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References

Ahern J., 2007. Green infrastructure for cities: The spatial dimension. Cities of the Future: Towards Integrated Sustainable Water and Landscape Management, 267–283.

Benedict M.A., McMahon E.T., 2002. Green Infrastructure: Smart Conservation for the 21st Century. Renewable Resources Journal (20), 12–17.

Dawson R., Wyckmans A., Heidrich O., Köhler J., Dobson S., Feliu E. (ed.), 2014. Understanding Cities: Advances in Integrated Assessment of Urban Sustainability. Centre for Earth systems Engineering Research (CESER), Newcastle

EEA, 2011. Green infrastructure and territorial cohesion. The concept of green infrastructure and its integration into policies using monitoring systems. Publications Office of the European Union, Luxemburg.

EEA, Spatial analysis of green infrastructure in Europe. Publications Office of the European Union, Luxemburg.

European Commission, Communication From The Commission To The European Parliament, The Council, The European Economic And Social Committee And The Committee Of The Regions: Green Infrastructure (GI) – Enhancing Europe's Natural Capital, COM, Brussels.

Firehock K., Walker R.A., 2015. Strategic Green Infrastructure Planning. A Multi-scale Approach. Washington, Covelo, Islandpress, London.

Foster J., Lowe A., Winkelman S., 2011. The Value of Green Infrastructure for Urban Climate Adaptation. The Center for Clean Air Policy, Washington.

Liquete C., Kleeschulte S., Digec G., Maesd J., Grizzettia B., Olahe B., Zuliand G., 2015. Mapping Green Infrastructure Based on Ecosystem Services and Ecological Networks: A Pan-European Case Study. Environmental Science & Policy (54), 268–280.

METRO water services, US Army Corps of Engineers, 2009. Green Infrastructure Design Using Low Impact Development https://www.nashville.gov/Portals/0/SiteContent/GeneralServices/docs/Landscape-Manual/Green_Infrastructure_Design.pdf [5.08.2019].

Minister of Infrastructure, 2002. The ordinance of 12th April 2002, on technical conditions of buildings and its location, § 39.

Mubareka S., Estreguil Ch., Baranzelli C., Rocha Gomes C., Carlo Lavalle C., Hofer B., 2013. A Land-use-based Modelling Chain to Assess the Impacts of Natural Water Retention Measures on Europe's Green Infrastructure. International Journal of Geographical Information Science 27(9), 1740–1763.

Ociepa-Kubicka A., 2014. Rola planowania przestrzennego w zarządzaniu ochroną środowiska. Engineering and Protection of Environment (17), 135–156.

Pirowski A. 2014. Zielona infrastruktura w największych miastach europejskich – ocena i porównanie potencjału Warsaw University of Life Sciences – SGGW, Warsaw.

Resolution No XI/221/03 of the City Council of Wrocław of July 11, 2003 on the adoption of local spatial development plan of Marszowice Malownicze III, Wrocław.

Resolution No XLIX/3118/06 of the City Council of Wrocław of April 6, 2006 on the adoption of local spatial development plan of Stabłowice Stare I and III urban unit, Wrocław.

Resolution No LVI/1727/10 of the City Council of Wrocław of November 4, 2010 on the adoption of local spatial development plan of South Swojczyce urban unit, Wrocław.

Resolution No XXXI/703/12 of the City Council of Wrocław of September 13, 2012 on the adoption of local spatial development plan of north part of Targowa Trasa, Wrocław.

Resolution No LXII/1599/14 of the City Council of Wrocław of September 4, 2014 on the adoption of an amendment to the local spatial development plan of Marszowice Malownicze III, Wrocław.

Resolution No VII/85/15 of the City Council of Wrocław of February 12, 2015 on the adoption of local spatial development plan of the area of Wojanowska, Daktylowa, Arachidowa and Piotrkowska streets, Wrocław.

Resolution No XVII/314/15 of the City Council of Wrocław of October 15, 2015 on the adoption of local spatial development plan of the area of Alfreda Jahna, Teofila Modelskiego, Józefa Wąsowicza, Władysława Czaplińskiego, Stanisława Bąka i Iwo Jaworskiego streets, Wrocław.

Resolution No L/1177/18 of the Municipality Council of Wrocław of January 11, 2018 on the adoption of study on land use planning.

Sandström Ulf G. 2002. Green Infrastructure Planning in Urban Sweden. Planning Practice & Research 17, 4, 373–385.

Szulczewska B. 2018. Zielona infrastruktura – czy koniec historii? Studies of KPZP PAN, CLXXXIX, KPZP PAN, Warsaw.

The Act of March 27, 2003 on spatial planning and development (consolidated text of 2018: position No 1945 with changes).

The Landscape Institute. 2009. Green infrastructure: connected and multifunctional landscapes. Landscape Institute Position Statement, The Landscape Institute, London.

Town and Country Planning Association and The Wildlife Trusts. 2012. Planning for a Healthy Environment – Good Practice Guidance for Green Infrastructure and Biodiversity. Town and Country Planning Association and The Wildlife Trusts, London.

Zaborowski T., 2012. Kształtowanie koncentracji osadnictwa w polityce zrównoważonego rozwoju przestrzennego. Porównanie ustaleń polityki przestrzennej obowiązującej w regionach miejskich Bristolu, Hanoweru i Wrocławia. Wrocław University of Science and Technology, Wrocław.

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Green Architecture in Switzerland

Zielona architektura w Szwajcarii

Abstract

This paper fly over the current situation of green infrastructures in Switzerland – a country with high environmental awareness which aims to create a sustainable urban ecosystem. In order to achieve that goal, cities ought to consider integrating vegetation in new and old buildings as well as create more green spaces in fast growing cities. This paper will introduce a few possible applications of greenery in architecture by presenting eight projects in Switzerland that solve problems such as excessive energy consumption, poor air quality, low attractiveness of a building, increased noise, overheating of the building, disturbed urban ecosystems or lack of social space by using green solutions. For better comprehension of the political context in which these examples where built a part of the Swiss construction policy will be explained.

Streszczenie

Artykuł przedstawia obecny rozwój zielonej architektury w Szwajcarii – kraju o wysokiej świadomości ekologicznej, który ma na celu tworzenie zrównoważonego ekosystemu miejskiego. Jednym ze sposobów na jego osiągnięcie jest zintegrowanie zieleni z architekturą i wytworzenie nowych terenów zieleni w szybko rozwijających się miastach. Artykuł omawia możliwe zastosowania zieleni w architekturze poprzez dokonanie analizy ośmiu projektów ze Szwajcarii, w których wykorzystano zieloną architekturę do rozwiązania problemów takich jak: nadmierne zużycie energii, zła jakość powietrza, niska atrakcyjność budynku, nadmierny hałas, nadmierne nagrzewanie się budynku, zaburzenia w ekosystemie miejskim czy brak części socjalnej. W celu lepszego zrozumienia kontekstu politycznego, w którym projekty te były wykonywane, opisano regulacje prawne dotyczące zielonej architektury w Szwajcarii.

Key words: green city, green architecture, green roof, green facade, Switzerland
Słowa kluczowe: zieleń w mieście, zielona architektura, zielone dachy, zielone elewacje, Szwajcaria

1. Introduction

Cities in Switzerland are constantly developing. The population density is increasing; and the expectation are high standards. Swiss legislation limits new development areas (Bundesgesetz über die Raumplanung) therefore there is a tendency to dense the city and build up. Switzerland aims to maintain a good environmental quality therefore it is searching for new solutions to create ecological cities. One of the solutions is to introduce more green areas. Due to free space limitation, there is a tendency to implement greenery in alternative ways, such as on roofs and façades. New technologies available for designing green architecture help to integrate plants with the buildings and to minimize building's demand for heating and cooling. Green architecture allows to reduce energy consumption and sound level, as well as it improves air quality in cities (Arup Company 2016). Moreover, presence of greenery has a huge impact on citizens' well-being (Schröpfer et al. 2016).

Creating green façades is one of the many ideas to make cities greener and there is a huge potential to raise the number of façades integrated with greenery. The advantage of this solution is that it could be implemented regardless of building density and due to a variety forms of green façades, it could be used on different types of buildings (Pfoser 2018). Designing green roofs and green façades would bring desired results only if created in accordance with regional ecosystems. The greenery should match neighbourhood nature so as to allow local insects and animals to survive (Dürst 2018).

Creating green architecture has become an important issue in Switzerland and more and more examples appearing of introducing well designed green architecture to cities. This article aims to present selected examples of architectural buildings in Switzerland which are integrated with greenery and to analyze the benefits of such integrated solutions.

2. Green architecture in Switzerland

2.1. Legal conditions

Designing green architecture has become legally regulated. For example, rainwater that is not contaminated, should be absorbed, for which green areas are needed (Bundesgesetz über den Schutz der Gewässer GSchG, Art. 7). Fees are charged, if rainwater is drained to the sewage system (Anschluss – und Abwasserentsorgungsgebühren. bern.ch).

Since 1991, a building law of Zurich has introduced a recommendation to vegetate roofs. In 2005, the law has specified that the greenery on roofs should have ecological value. Moreover, if solar systems on roofs exist, the roof should also be vegetated (Bauordnung der Stadt Zürich, Art. 11). The law proposes how flat roofs should be vegetated:
1) A layer of permeable planting soil should be at least 10 cm thick;
2) There should be a qualitative soil, that can absorb water;
3) A soil mound of at least 3 m diameter per 100 m^2 should be 20 cm high or it should be 10% of the green surface;
4) The roof should be covered with quality plants from the CH-Ökotypen (Swiss ecotypes) (Stadt-zuerich, Dachbegruenung).

While designing a green roof, a higher hill of soil can be added where a wall under the roof or a structural pillar is placed. This solution allows a diversity of vegetation to be planted. Green roofs should also contain branches of wood and roots which can be used as a shelter for insects. Solar panels combined with green roofs (Fig. 1) are cooled by greenery. Moreover, the panels throw a shadow, giving life to other kinds of plants (Dürst 2018).

Whilst Swiss cantons and communes have different legislation concerning green architecture, in every big city it is mandatory to implement greenery.

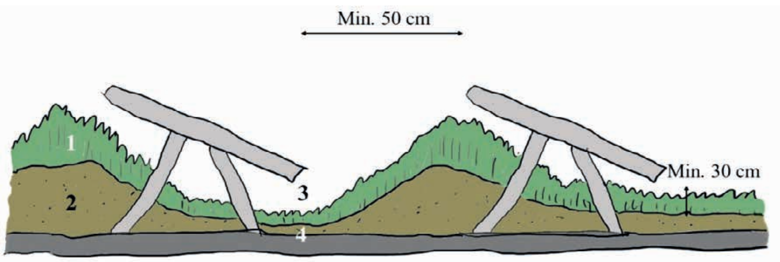

Fig. 1. The complementary role of plants to solar panels:
1. Plants on the raised hill grow faster, higher and there is a large selection of plants,
2. More soil does not dry out so quickly, there is more room for the plant roots,
3. Plants grow slower and they are smaller, there is little choice of plant types,
4. Soil dries quickly and there is little room for roots.
(Source: own study based on Dürst 2018)

Ryc. 1. Komplementarna rola roślin do paneli słonecznych:
1. Rośliny na wzniesieniu rosną szybciej i wyżej, jest duży wybór roślin.
2. Większość ziemi nie wysycha tak szybko, jest więcej miejsca dla korzeni roślin.
3. Rośliny rosną wolniej i są mniejsze, nie ma większego wyboru rodzajów roślin.
4. Gleba szybko wysycha i nie ma zbyt wiele miejsca na korzenie.
(Źródło: opracowanie własne na podstawie Dürst 2018)

2.2. Swiss tradition of greening buildings

One of the oldest examples of green roofs in Switzerland is the water treatment plant building “Seewasserwerk Moss” in Zurich. This building from 1914 has three roofs with a total area of three hectares. It is covered with a 5 cm drainage layer of sand and a 20 cm layer of soil. The green roofs were to lower the temperature of the concrete building halls. Currently, the green roofs are home for 175 different plant species, including rare orchids (Greenroofs, Moos Water Filtration Plant).

Another example of green roofs and façades was built in 1962 and can be found on the

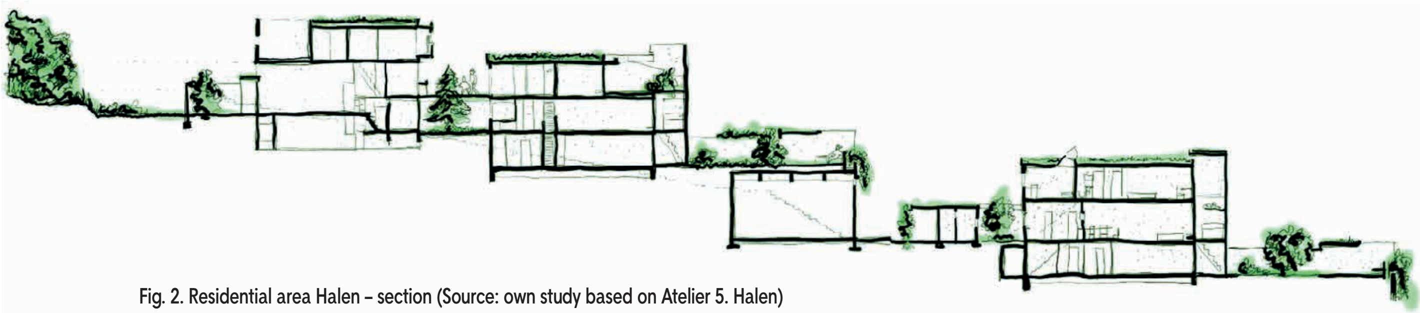

Fig. 2. Residential area Halen – section (Source: own study based on Atelier 5. Halen)

Ryc. 2. Osiedle Halen – przekrój (Źródło: opracowanie własne na podstawie Atelier 5, Halen)

Hales residential area, in Herrenschwanden, near Bern. The residential area was built by the architectural office – Atelier 5. This residential area is an important example of 20th century Modernism and it is on the list of cultural assets of national importance. The challenge of this project was to create compact buildings, while maintaining a high comfort of life. The residential area is located on a hill in a forest, with a view on the mountains. The apartments are narrow but each of them has three floors and two gardens. The terrace construction allows each apartment to have a view of the mountains. Moreover, every roof is covered with greenery, which allows habitants to have an undisturbed view of nature (Atelier 5, Halen). The entrances of the buildings are roofed and separated from the street by trees or climbing plants on metal lines (Fig. 2).

The Halen residential area was a great success that lead to build other residential areas with similar solutions. One example is the residential area – Thalmatt 2, built in 1985 (Atelier 5, Thalmatt 2). Here, the architects implemented metal arches which allow plants to climb and provide some shadow to the balconies (Photo 1). Roofs and elevations of the buildings are covered with greenery.

Today, green roofs are mandatory in the cities and green façades are being built by private investors. Depending on the purpose, different approaches to implement green architecture on buildings can be applied. One of the solutions that is currently tested in Switzerland is called "Skyflor". It is an easy way to install modular element of green façades, which is not difficult to take care of and which, due to a ceramic structure through which the plants grow, it is visually attractive (Photo 2). Other contemporary examples of green infrastructure will be shown and analyzed in the next chapter.

Photo. 1. Residential area Thalmatt 2 (Author's collection)

Fot. 1. Osiedle Thalmatt 2 (zbiory autorki)

Photo. 2. Skyflor Module (Source: http://skyflor.ch)

Fot. 2. Moduł Skyflor (Źródło: http://skyflor.ch)

2.3. Description of selected examples of green architecture

There are different forms of green infrastructure. The way of designing Green Architecture depends e.g. on the project, the surrounding and the purpose of the building. This chapter will show some examples of using green infrastructure to shape a construction. Thanks to the implementation of greenery on buildings a new green space was created, and an architectural problem was solved.

2.3.1. Museum der Kulturen, Basel

Architect: Herzog & de Meuron, Basel
Construction time: 2008–2011
Address: Münsterpl. 20, 4051 Basel
Main achievements: Creation of a new exhibition space by perfectly blending a contemporary architecture with its historical surroundings.

Short description of the project: The object is intended for museum purposes. On top of a historical building a new exhibition space was designed. The space is covered with a modern roof under which a construction with growing plants is suspended (Photo 3). The basement of the building was transformed into an entrance (Herzog & de Meuron, Museum der Kulturen Basel).

Photo 3. Entrance to Museum der Kulturen, Basel (Author's collection)

Fot. 3. Wejście do „Museum der Kulturen", Bazylea (zbiory autorki)

Building analysis: The purpose of the modernisation was to give a new image to the Cultural Museum. The new entrance is connected with a medieval square. The square in front of the museum has been restored for use with the intention of becoming a 'green oasis'. Designing a modern roof with a hanging structure for climbing plants gave the old building a new image. The green creepers change the building's proportions by dividing the historical façade into two smaller parts (Fig. 6). Due to this solution, the building fits better into the space of small wooden tenements. Furthermore, the creepers partially cover the façade where some windows have been removed, which rises the building's aesthetics (Fierz 2011).

Conclusions: The new solution, that connects a part of the building using vegetation gives the façade a new character. The vegetation helped to change the building's proportions and to adjust its dimensions to the surrounding houses. Moreover, the suspended greenery hid the bricked-up windows, thus achieving an aesthetic harmony. As the structure for greenery is hanging and it does not touch the ground, most of the square could be utilized. Thanks to the new proportions and green elements, the square has become very cozy.

2.3.2. Garden Tower near Bern

Architect: Buchner Bründer Architekten, Basel
Construction time: 2014–2016
Address: Bächtelenweg, 3084 Köniz
Main achievements: Creation of attractive apartments with balcony and a new green area while naturally protecting the building from the sun.

Short description of the project: The building has a polygonal plan, and is surrounded by balconies of approximately 3 m each, which have integrated pots for climbing plants.

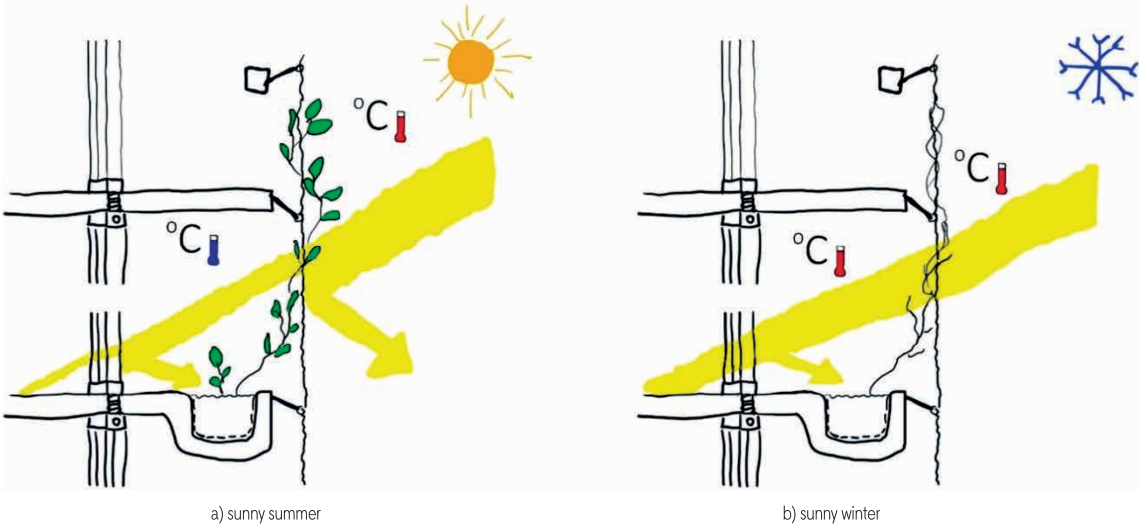

Fig. 3. Influence of seasonal climbers on the indoor temperature: a) sunny summer, b) sunny winter (Source: own study)

Ryc. 3. Wpływ sezonowego bluszczu na temperaturę wnętrza: a) słoneczne lato, b) słoneczna zima (Źródło: opracowanie własne)

The plants grow on a metal mesh attached to a metal bracket. At the bottom of the pot it either has the height of a normal railing or reaches the next floor. The different heights of the meshes give rhythm and character to the building (Detail 5/2018, p. 42).

Building analysis: The building has received the first price for a residential tower design in Wabern (Buchner Bründer Architekten, Garden Tower) In order to refer to the neighbouring green and agricultural areas, the building is covered with greenery. The main function of the climbing plants is to provide some shadow to the balconies and the interiors of the apartments. In summer the plants cool down air and in winter they let the sun in as their leaves fall (Fig. 3).

Conclusions: The main idea of the residential building was to integrate greenery where plants protect interiors in summer from excessive heat. The architects have created a new space for greenery by placing it around the building. With this solution, the concrete does not heat up excessively and the air is cooled in the process of evaporation. Moreover, the plants clean the air from dust, and they produce oxygen. Thanks to the green façade, the building fits well to the green area, which is eagerly inhabited and highly valued by the residents of Bern. As the plants grow on balconies, they are easily accessible and simple to take care of. The plants which were chosen to grow, change colors and shape depending on the season, giving the façade different appearances. Moreover, the inhabitants can choose the plants that they want to grow. The building has been given added value because it has created a new green space in which people are willing to live.

2.3.3. Aglaya

Architect: Ramser Schmid Architekten, Zurich
Construction time: 2018–2020
Address: Suurstoffi 37, 6343 Risch-Rotkreuz
Main achievements: Creation of a green area for apartment residents that brings a high ecological value to the building as the plants clean and cool the air.

Short description of the project: The building is 70 m high and it contains 85 high standard apartments for sale as well as places for shops, restaurants and offices. There are plants and trees on balconies aiming to make people feel as if they were in a garden (Aglaya, Natur wächst vom Haus aus).

Building analysis: The residential tower is built in the Suurstoffi district, where cars are not allowed. This district targets to have energy saving buildings and to limit carbon dioxide production (Aglaya, Natur wächst vom Haus aus). Therefore, the building which is still under construction will integrate plants on the balconies in order to produce oxygen and clean air from the dust. The building was inspired by a pioneering project created in 2009–2014 in Milan, Italy, by Stefano Boeri: two skyscrapers, called “Bosco Verticale”, that have grooving trees on their balconies. The analysis of the Italian building showed that this solution efficiently cleans and cools the air, as well as reduces noise. Moreover, it is a habitat for insects and birds to live (Stefano Boeri Architetti, Bosco Verticale).

Conclusions: The idea to plant trees on balconies is more and more often used as it provides humidified and dust-free air. Also, by using plants from the region, the green area on balconies provides a habitat for insects and birds. The greenery improves the well-being of the residents and give higher value to the building.

2.3.4. Kalkbreite, Zurich

Architect: Müller Sigrist Architekten AG, Zurich
Construction time: 2014
Address: Kalkbreitestrasse 2, 8003 Zurich
Main achievements: Transforming an existing urban space into a more efficient and green living space.

Short description of the project: A 2500 m^2 public terrace was designed on the roof of the tram depot, as a recreation area for the population. Around the depot, there are multi-family houses and in the lower part of the building, there are restaurants, offices and shops. The Kalkbereite housing estate is a good example of sustainable construction in Zurich and has recently received an architectural award given by the canton of Zurich (Mobilservice 2016).

Building analysis: The building has transformed the tram depot into a well-functioning social space by creating a new green area available to the public (Kalkbreit, Architektur). Moreover, there is a social space for the residents on the roof one the building, where they can interact with each other while growing fruits and vegetables (Fig. 4).

Conclusions: The space is better organised, creating sustainable architecture. The valuable space in the city center is used better, and its quality has risen. Furthermore, the tram depot has become a social and ecological living space.

2.3.5. Stücki Shopping, Basel

Architect: Diener & Diener Architekten
Construction time: 2001–2009
Address: Hochbergerstrasse 70, 4057 Basel
Main achievements: Creation of a housing estate with a large shopping centre in the industrial area by utilising the green façade. Creating an identification of the building and an intimate atmosphere.

Short description of the project: In the building there is a shopping center, offices, a hotel and a parking, taking up 98 000 m^2 space. There are pots with climbing plants on balconies on the south-eastern façade and climbing plants planted on the ground on the northwest façade (Photo 5) (Diener Diener Architekten, Shopping Center Stückfärbere).

Building analysis: The main entrance of the building is not parallel to the road nor the river but to the industrial buildings, which are located on the east side of the building, creating two squares in front of the building where the entrance and restaurants are placed

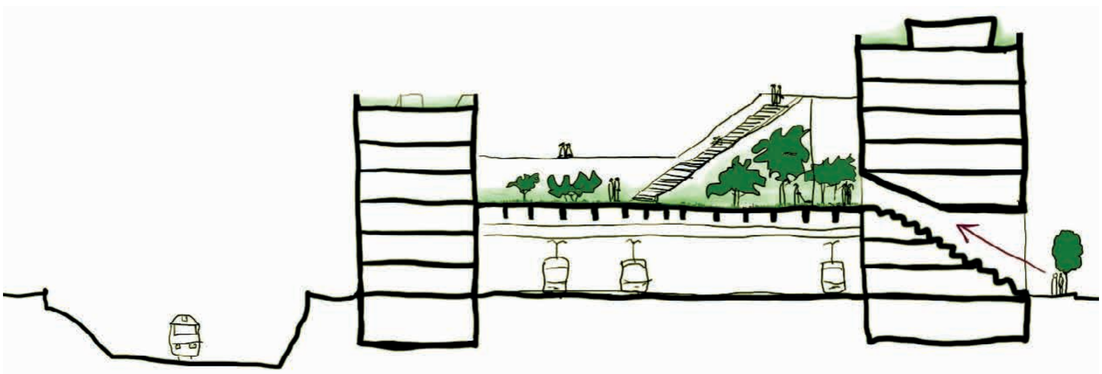

Fig. 4. On the section is visible the tram depot with the green terrace on its roof (Source: own study)

Ryc. 4. Na przekroju widoczna jest zajezdnia tramwajowa z zielonym tarasem na dachu (Źródło: opracowanie własne)

(Diener Diener Architekten, Shopping Center Stückfärbere). On the main southeast façade, there are long balconies with pots of climbing plants. The greenery on the building gives the feeling that the commercial building has the same scale as the residential area and blends it into the surroundings (Photo 6).

Conclusions: The green façade, the large building seems smaller integrating itself with the housing estate. The interesting façade attracts modifying the building into a well recognizable iconic place.

Photo 5. Shelving system. Mein entrance by Stücki Shopping, Basel (Source: R. Lehmann)

Fot. 5. System półkowy. Główne wejście do centrum handlowego Stücki, Basylea (Źródło: R. Lehmann)

2.3.6. Alpine Finanz, Opfikon

Landscaping architect: Raderschallpartner AG +Firma Jakob
Address: Sägereistrasse 20, 8152 Glattbrugg
Main achievements: Reduction of the noise level and sun protection.

Short description of the project: A metal construction situated about 5 m from the building on the south-eastern side contains climbing plants from the ground.

Building analysis: The green wall provides shadow to the building. It is beneficial for the offices, as intensive sunlight disturbs computer work. Moreover, the green façade cools the building due to the shadow and the evaporation process of plants. This solution lowers the cost of air conditioning up to 35% in summer (Heinze, Jakob). During the winter the sun gets into the building, as the plants have no leaves warming up the interior of the building. The space between the green wall and the building is used for

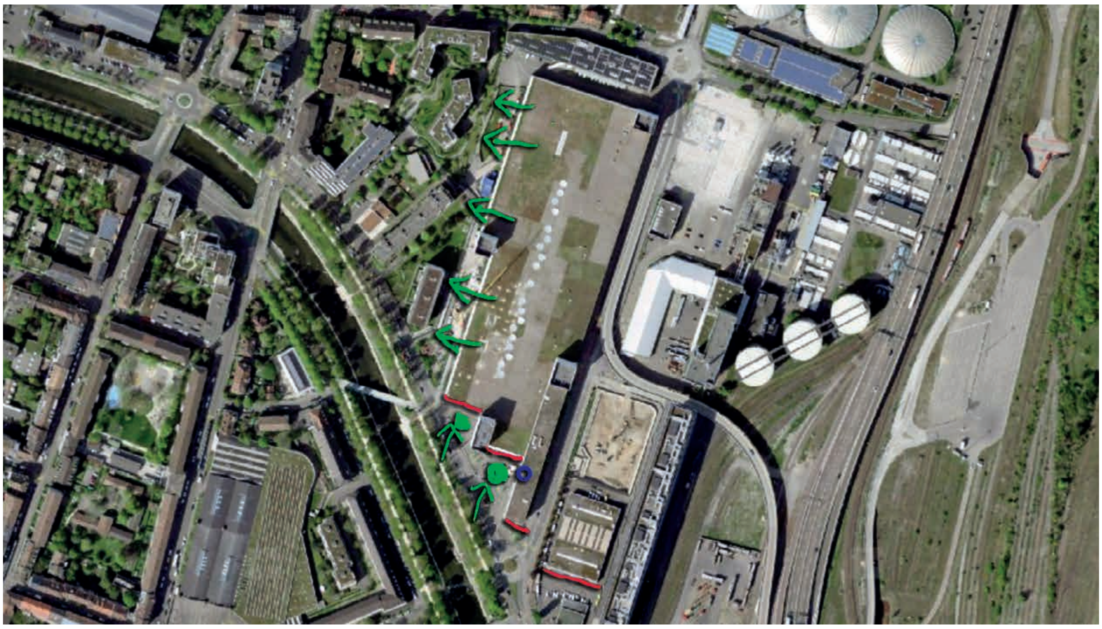

Photo 6. A top view shows that the facade is parallel to the factory building and forms two squares. The green facade opens towards the residential area (Source: Bundesamt für Landestopografie)

Fot. 6. Widok z góry pokazuje, że elewacja jest równoległa do budynku fabrycznego i tworzy dwa place. Zielona elewacja otwiera się w stronę osiedla mieszkaniowego (Źródło: Bundesamt für Landestopografie)

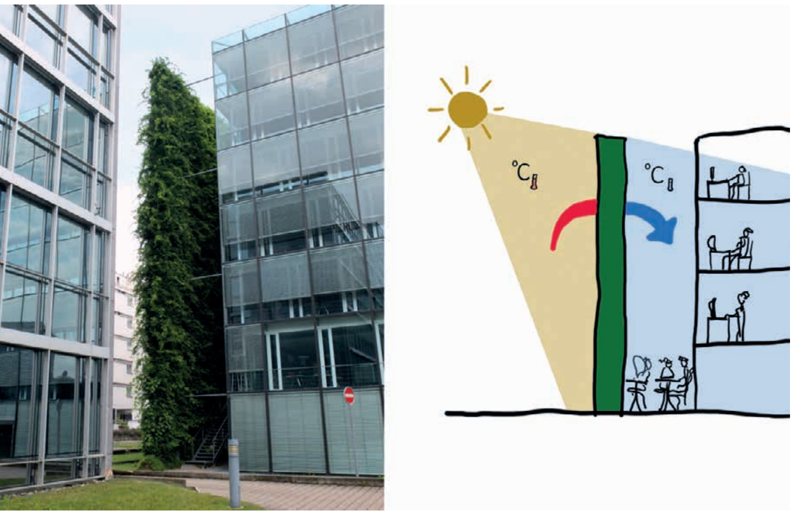

Photo 7. A green wall that throws a shadow on the building and cools the air in summer (Source: own study)

Fot. 7. Zielona ściana, która rzuca cień na budynek i ochładza powietrze w lecie (Źródło: opracowanie własne)

Photo 8. Picture of the courtyard with a pergola (Author's collection)

Fot. 8. Zdjęcie podwórza z pergolą (zbiory autorki)

restaurants (Photo 7). Moreover, the green membrane reduces the noise of the planes taking off from Zurich Airport situated not far from the building. The green wall is part of the building and it is regulated by building regulations.

Conclusions: The green wall protects the building, bringing shade in the interior spaces, cools the air, and reduces noise. Plants grow directly from the ground, so it is relatively easy to maintain the façade. On the other hand, such a structure needs a lot of space of the ground floor. This solution is best suited to medium height buildings, because the plants can grow up to 20–25 m.

2.3.7. Zweierstrasse 38A, Zurich

Architect: Kistler Vogt Architekten AG, Biel
Construction time: 2016
Address: Zweierstrasse 38A, Zurich
Main achievements: To blend into surroundings of tenement houses and provide dense buildings with compact apartments. In the intensively built-up space, an additional green recreational space was created for the inhabitants of the estate. Improved view from the windows.

Short description of the project: The building has five to six floors. Containing 40 compact apartments from 2.5 to 4.5 rooms and some facilities on the ground floor. The building is located in the centre of Zurich and has the shape of a plot. In the center, there is a courtyard where an old laundry building is located, its extension is a newly built pergola on which plants climb. The façade is covered with ivy on the side of the yard. Under the building there is underground parking (Kistler Vogt Partner, Wohnüberbauung Gartenhof).

Building analysis: In the courtyard on the opposite side, the buildings are in close distance from each other. A pergola was built in the middle of the courtyard to improve the view. Since there is parking under the courtyard, it is not possible to plant trees. The only possibility was to plant species which do not require too much soil. Under the pergola there is a room for inhabitants to meet. Green curtains are a place that gives a shadow and reduces noise. Ivy on the elevation completes the green square (Photo 8).

Conclusions: Despite the highly dense built-up space, the architect created a green area for the residents. This space is well designed and used, giving a cozy character to the courtyard. The greenery has a protective function, covering the space under the pergola, shading and soundproofing it. The pergola also provides a better view from windows.

2.3.8. MFO-Park, Zurich

Architect: Burckhardt + Partner Architekten
Construction time: 2002
Address: MFO-Park, 8050 Zurich
Main achievements: Creation of a larger recreational space due to thinking in three dimensions. Creating additional space for greenery in the city center.

Short description of the project: The large "park house" has a double-walled construction covered with wire mesh and supported with footbridges, stairs and supplemented with balconies. All is covered with a variety of lushly growing and fragrant climbing plants (Photo 9). Rainwater is fed to the roots. Excess water seeps out to the underground storage canal. The MFO-Park is 100 meters long, 34 meters wide and 18 meters high (Burckhardt + Partner Architekten, Neubau MFO-Park Zürich).

Building analysis: The spatial park has taken the dimensions of a former factory. The architects proposed to use the space as efficiently as possible. They created 17 m of pergolas, with balconies, terraces and viewpoints overlooking the city Centre of Zurich. The ground floor of the park is a large multifunctional square. The park looks different all year round. In winter the leaves fall, allowing the structure of the park to be seen.

Conclusions: It depicts a visible change of thinking from 2D to 3D, where the park is designed vertically, and it has many levels at different heights. The new space for greenery is dense.

Photo 9. MFO-Park (Author's collection)

Fot. 9. MFO-Park (zbiory autorki)

3. Conclusions

The article illustrates that the integration of plants on buildings is a well-known practice in Switzerland. In all projects discussed, the use of greenery does not only have technical purposes but also aesthetic.

Today, green architecture is becoming more and more popular not only because it introduces new aesthetic values but also because it is necessary to improve the quality of living in cities. Green flat roofs lower temperature and decrease the level of noise in cities while green infrastructures regulate and retain rainwater, clean air and produce oxygen. Through the densification of cities, natural green areas are becoming sparse and alternatives way of creating parks need to be found, such as three-dimensional parks that place greenery and recreational areas on different levels (i.e. MFO Park) or new green public squares created on existing roofs, such as in the Kalkbreite multifamily housing estate project.

Green areas also improve people's well-being. Unfortunately, not everyone in the city can afford a house with a garden. However, with today's technology even buildings can have green balconies allowing everyone to have their own private green area. Green balconies can be shaped in different ways, i.e. by placing pots on the balcony with greenery or by integrating these pots within the building. In such pots you can plant trees or climbing plants that can be directed by the supporting construction. The greenery on the balcony also helps to shape the façade, and this façade will change through the season. This can be seen on the Garten Tower, Aglaya and Shoppingcenter Stücki.

Integrating greenery also shapes buildings and rises their aesthetic qualities. In the Kunst Museum, the greenery hanging from the roof gives the building new proportions, emphasizing the main entrance of the museum and providing a pleasant character to the square in front of the museum. Similarly, on the Stücki shopping center, the greenery changes the proportions of the building and gives a cozy atmosphere to the squares in front of the building, inviting people to enter shops and restaurants. Both façades became recognizable due to the greenery implementation and their surrounding received a new aesthetic value.

The green envelope also has an impact on the technical infrastructure of the building. It protects the building from changing weather conditions, and it reduces energy consumption. The green envelope quietens environment by absorbing sound. It attracts birds allowing inhabitants to enjoy the sound of birds singing. Green infrastructure regulates rainwater by keeping water on the plot for a longer period and reusing it for watering the greenery. The vegetation can also regulate the sunlight inside the building by creating a green curtain of climbing plants. This solution is used on the Garten Tower and Alpine Finanz center.

The table below (Tab. 1) shows the key goals that can be achieved by implementing green infrastructure on a building and those obstacles that need to be overcome to create more of these green buildings in Switzerland.

Table 1. The goals that can be achieved by implementing green architecture and the obstacles leading to these goals (Source: own study)

Tabela 1. Cele, które można osiągnąć poprzez wdrożenie zielonej architektury oraz przeszkody utrudniające ich osiągnięcie (Źródło: opracowanie własne)

Environment	
Goals	Cities are less heated and do not have negative impact on climate Air is cleaner and there is more oxygen Water is kept longer in cities and it improves its microclimate Green areas are restored in cities Biodiversity is improved Green areas in cities are integrated with those outside, enabling migration of animals and insects Ecological balance is restored
Obstacles	High costs of implementing green infrastructure Lack of ecological and technical know-how Green infrastructure has positive impact only if introduced on a large scale
City	
Goals	Attractiveness of the cities is increased Cities are densified without losing quality for inhabitants New, attractive green space is created More green areas Cities are integrated with nature Temperature and noise are reduced More oxygen and less dust Water retention Healthier citizens
Obstacles	High costs of implementing green infrastructure Lack of regulation The need to take care of the green infrastructure Redevelopment of urban infrastructure
People	
Goals	People feel better in cities People relax better in the green areas Greenery and nature attract people to each other People are healthier because of higher air quality and less noise People integrate in parks and recreation areas People have higher sensitivity to the environment around them
Obstacles	Little awareness of people Lifestyle change

Table 1. Cont.

Tabela 1. Cd.

Architecture	
Goals	Green space for people is created Higher quality of designed space Higher value of buildings Buildings are integrated with surrounding Buildings are shaped by implemented green infrastructure: ▪ Aesthetics of a building is improved, ▪ A facade is shaped, ▪ Proportions and scale are changed, ▪ Architectural elements are highlighted or covered up, ▪ A building is changed according to changing seasons, ▪ Heating of buildings is regulated by sun's light: – Energy consumption is reduced, – Sunlight inside the building is regulated, Buildings are protected against external factors Rainwater is regulated
Obstacles	High costs of implementing green infrastructure Lack of ecological and technical know-how High costs of maintaining green architecture

References

Aglaya, Natur wächst vom Haus aus. https://www.aglaya-rotkreuz.ch/projekt#!/ [15.04.2019].

Arup, Green building envelope, Berlin. https://www.arup.com/perspectives/publications/research/section/cities-alive-green-building-envelope [2016.09].

Atelierr 5, Siedlung Halen, Herrenschwanden. https://atelier5.ch/arbeiten/1961-siedlung-halen-herrenschwanden?cat=2&cHash=f1b3453f3dcb5a0810a5aec84e577429 [01.09.2019].

Atelie 5, Siedlung Thalmatt 2, Herrenschwanden. https://atelier5.ch/arbeiten/1985-siedlung-thalmatt-2-herrenschwanden?cat=2&cHash=490f0c178373ca7e4dc1e272a02f4ef4) [01.09.2019].

Buchner Bründer Architekten, Garden Tower. https://bbarc.ch/de/garden-tower?cat=Bau [15.04.2019].

Burckhardt + Partner Architekten, Neubau MFO-Park Zürich. https://www.burckhardtpartner.com/de/projekte/detail/projekte/show/Projekte/neubau-mfo-park-zuerich/ [01.09.2019].

Diener Diener Architekten, Shopping Center. Stückfärbere.http://www.dienerdiener.ch/en/project/shopping-center-stueckfaerberei [01.09.2019].

Dürst U. et al., 2018. Grüne Dächer und Fassaden für Zürich In Grün am Bau. Grün Stadt Zürich. https://www.abenteuer-stadtnatur.ch/?q=node/178 [2018.05].

Garden Tower near Bern. Detail 5/2018 – Facades, 42–46.

Fierz G. et al., 2011. Intrinsic Perspectives. From Mis Kumbuk to Herzog & de Meuron. Museum der Kulturen Basel.

Greenroofs, Moos Water Filtration Plant. https://www.greenroofs.com/projects/moos-water-filtration-plant-seewasserwerk-moos/ [01.09.2019].

Heinze, Jakob Green Solutions – Rankstrukturen für die Begrünung. https://www.heinze.de/produktserie/jakob-green-solutions-rankstrukturen-fuer-die-begruenung/18599943/2/ [01.09.2019].

Herzog & de Meuron, Museum der Kulturen Basel. https://www.herzogdemeuron.com/index/projects/complete-works/176–200/200-museum-der-kulturen.html [01.09.2019].

Kalkbreite, Architektur. https://www.kalkbreite.net/kalkbreite/architektur-kalkbreite/ [01.09.2019]

Kistler Vogt Partner, Wohnüberbauung Gartenhof. https://www.kistler-vogt.ch/projekte/wohnueberbauung-gartenhof-zuerich-zh/ [01.09.2019].

Mobilservice, Studie zur Siedlung Kalkbreite in Zürich: Nachhaltiges Wohnen funktioniert. https://www.mobilservice.ch/de/home/news/news-dossiers/studie-zur-siedlung-kalkbreite-in-zuerich-1648.html [05.09.2016].

Pfoser N., 2018. Vertikale Begrünung. Ulmer.

Schröpfer, T. et al., 2016. Dense + Green. Innovative Building Types for Sustainable Urban Architecture. Birkhäuser.

Schweizerische Eidgenossenschaft, Bundesgesetz über die Raumplanung. https://www.admin.ch/opc/de/classified-compilation/19790171/index.html [01.01.2019].
Skyflor. http://www.skyflor.ch/home/ [01.09.2019].
Stadt-zuerich, Dachbegruenung. http://stadt-zuerich.ch/dachbegruenung [15.04.2019].
Stadt-zuerich, Vertikal Begruenung. http://stadt-zuerich.ch/vertikalbegruenung [15.04.2019].
Stad Bern, Anschluss- und Abwasserentsorgungsgebühren. www.bern.ch/themen/planen-und-bauen/anschluss-und-abwasserentsorgungsgebuhren [01.09.2019].
Stefano Boeri Architetti, Bosco Verticale. http://stefanoboeriarchitetti.net [13.10.2018].

Strashok Oleksandra[1], Kolesnichenko Olena[1], Lakyda Petro[1],
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Intensive green roofs RC "Smart Plaza Polytech" and RC "Royal Tower" (Kyiv): technology, plant assortment and their vitality

Intensywne dachy zielone KM "Smart Plaza Polytech" i KM "Royal Tower" (Kijów): technologia, asortyment roślin i ich żywotność

Abstract

The paper presents a detailed analysis of the most famous intensive green roofs on the skyscrapers in Kyiv. The authors analyzed the technology formation, plant assortment, and their biological characteristics. Moreover, presented results on evaluation of the illumination regime of plants and vitality analyses for better understand their functional aspects. The authors divided trees into three groups by the openness of the crown and the ability to transmit light into the lower horizons; evaluated such parameters as CRI, CCT, LUX, Delta Ascension, spectrum analysis and measurement of flicker. Found that the crown *Amelanchier lamarckii* better transmit the light and has higher illumination (Lux) of the soil under the crown among studied species. The results of the analysis of the light regime of crowns landscape architects can use to create phytocompositions for the selection of plants species, taking into account their requirements for the light regime. Established that all plants characterized by high vitality and decorative effect, only *Azalea* Jap. 'Marushka', *Hydrangea arborences* 'Anabelle' and *Rosa* cultivars had external features such as chlorosis as resulting from the lack of certain nutrients. In conclusion, 54 species and cultivars of plants are promising for cultivation on intensive green roofs in Kyiv that will support eco-stabilization processes of the environment in the city.

Streszczenie

Artykuł przedstawia szczegółową analizę najsłynniejszych dachów intensywnych na drapaczach chmur w Kijowie. Autorzy przeanalizowali tworzenie technologii, asortyment roślin i ich cechy biologiczne. Ponadto zaprezentowano wyniki oceny wpływu oświetlenia na rośliny i analizy żywotności w celu lepszego zrozumienia ich aspektów funkcjonalnych. Autorzy podzielili drzewa na trzy grupy ze względu na otwartość korony i zdolność do przekazywania

światła do niższych horyzontów; ocenili takie parametry jak CRI, CCT, LUX, Delta Ascension, analizę widma i pomiar migotania. Stwierdzono, że korona *Amelanchier lamarckii* lepiej przepuszcza światło i ma większe oświetlenie (Lux) gleby pod koroną wśród badanych gatunków. Wyniki analizy lekkiego reżimu koron architekci krajobrazu mogą wykorzystać do stworzenia fitoskładów do selekcji gatunków roślin, biorąc pod uwagę ich wymagania dotyczące reżimu lekkiego. Ustalono, że wszystkie rośliny charakteryzują się wysoką żywotnością i efektem dekoracyjnym, tylko *Azalea* Jap. 'Marushka', *Hydrangea arborences* 'Anabelle' i odmiany *Rosa* miały cechy zewnętrzne, takie jak chloroza, wynikające z braku niektórych składników odżywczych. Podsumowując, 54 gatunki i odmiany roślin są obiecujące do uprawy na intensywnych zielonych dachach w Kijowie, które będą wspierać procesy ekostabilizacji środowiska w mieście.

Key words: crown, illumination, resistance, winter hardiness
Słowa kluczowe: korona, oświetlenie, opór, odporność na zimę

1. Introduction

According to United Nations (2015) estimates, global climate change is a major problem for the world's population, which has a significant effect not only on destructive environmental processes, but also directly on people's living conditions. The scientists Bastin et al. (2019) predict that the climate of Madrid in 2050 will resemble the climate of Marrakech today; Stockholm will resemble Budapest, London – Barcelona, Moscow – Sofia, Seattle – San Francisco, Tokyo – Changsha. Green roofs are one of the methods of providing ecosystem services to cities characterized primarily by social impact.

The world's population will increase by about 2-fold by 2050, 60% of which will live in cities by 2030 (UNFPA 2007). The population of the city of Kyiv is approx. 3 million people (State Statistics Service of Ukraine). In recent years, the indices of construction activity in Kyiv indicate a slight decline, which in our opinion caused by the economic crisis (Fig. 1). Researchers Dunnett and Kingsbury (2004) noted that due to the arrangement of green roofs in cities it is possible to use 40–50% of the area of impervious territories.

Different government programs in the cities such as Portland, Helsinki, Toronto Berlin, Hong Kong and Melbourne encourage economic support for residents to build green roofs (Eunha, Heungsoon 2019; Adams et al. 2008; City of Toronto Report 2005; State of Victoria. Growing Green Guide 2014; Hui 2011). Furthermore, many active associations in European countries promote green roofs, including Germany, Switzer-

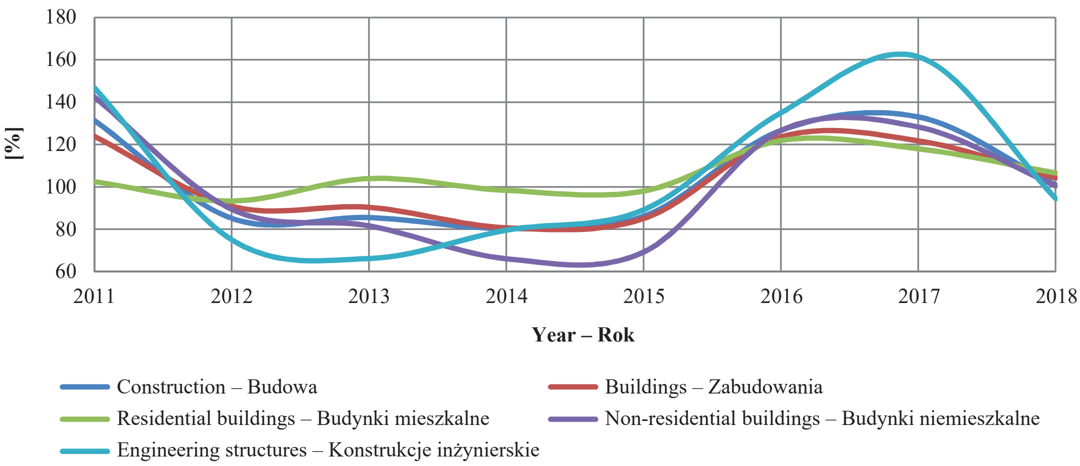


Fig. 1. Dynamics of indicators of change of construction production indices by type, % to the previous year (State Statistics Service of Ukraine)

Ryc. 1. Dynamika zmian wskaźników produkcji budowlanej według rodzajów,% w stosunku do roku poprzedniego (Państwowa Służba Statystyki Ukrainy)

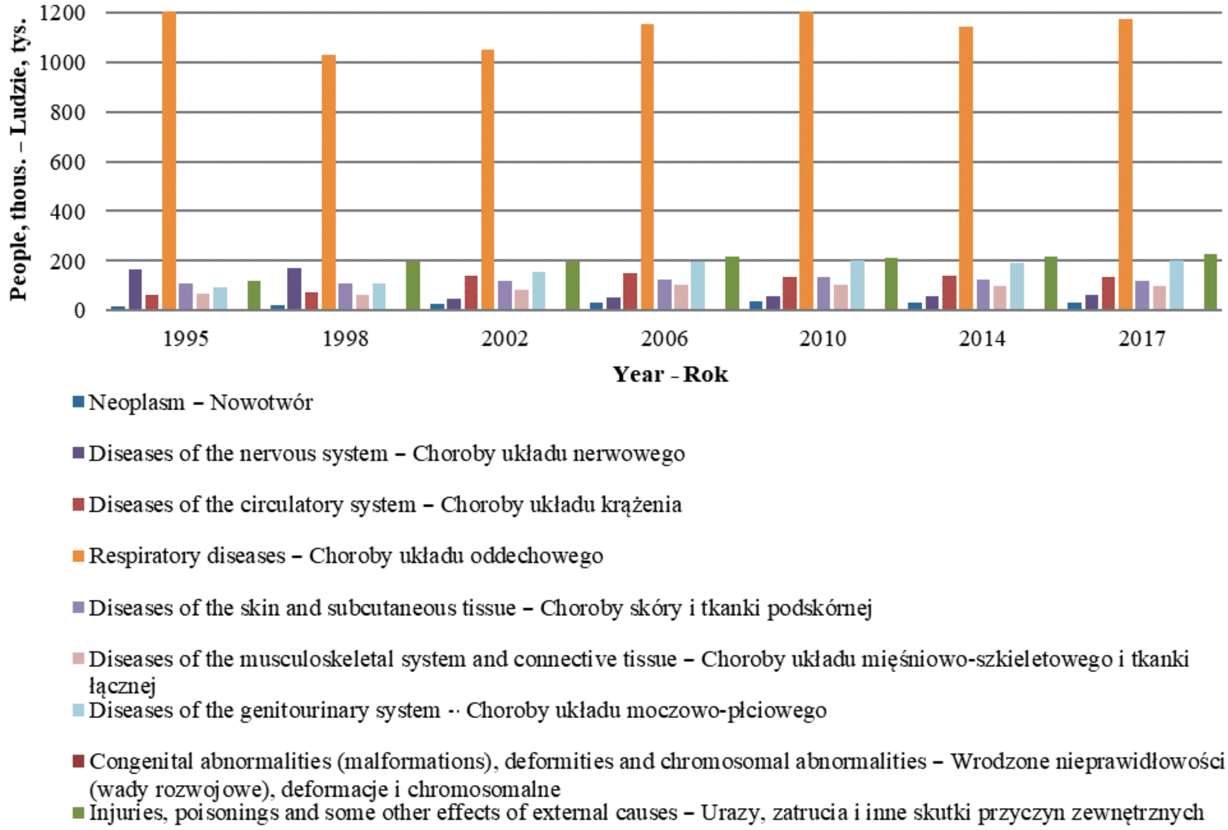


Fig. 2. Dynamics of the first registered cases of diseases among population of Kyiv, thous. (State Statistics Service of Ukraine)

Ryc. 2. Dynamika pierwszych zarejestrowanych przypadków chorób wśród ludności Kijowa, tys. (Państwowa Służba Statystyki Ukrainy)

land, the Netherlands, Norway, Italy, Austria, Hungary, Sweden, the United Kingdom and Greece.

Eunha and Heungsoon (2019) established that 100% introduction of green roofs as greening elements of cities in the best-case scenario exceeds costs with a benefit-cost ratio of 1.174, with worse – 1.0, which is also economically promising. The green roof installation in 2 times more expensive compared with traditional bitumen coating with operation period about 40 years (Nurmi et al. 2019).

XX century characterized by the emergence of a new environmental factor due to the rapid development of industry - man-made pollution of the environment. The WHO data demonstrate (2012) that due to air pollution in cities in developing countries happens more than 1 million premature deaths annually. After the Chernobyl disaster (1986), the number of respiratory diseases among Kyiv's population has declined for 10 years, but since 1996, there has been a sharp increase, which caused by an increase in the concentration of pollutants in the air (Fig. 2). Data Korea Forest Service (2011) shows that 1 m^2 of green roof can process 0.0052 kg/year NO_2, 0.0024 kg/year SO_2 and 0.0046 kg/year O_3. In research work Tumini (2014) notes that the reduction of the negative impact on the climate can be achieved through the correct selection of decoration materials for the horizontal surfaces of the city and emphasizes the benefits of green roofs: solar protection, natural cooling and heat efficiency.

Tkachenko et al. (2019) conducted studies about CO_2 concentration on green roofs and found that on green roofs the concentration of CO_2 (410–415 ppm) corresponds to the normal level in the outside air. For example, on an unpaved roof the concentration of CO_2 (452 ppm) slightly exceeds the upper concentration limit in the outside air. The results of studies Yang et al. (2008) indicate that 19.8 ha of green roofs absorb, in total, 1675 kg of various air pollutants per year, including O_3 accounting for 52% of the total NO_2 (27%),

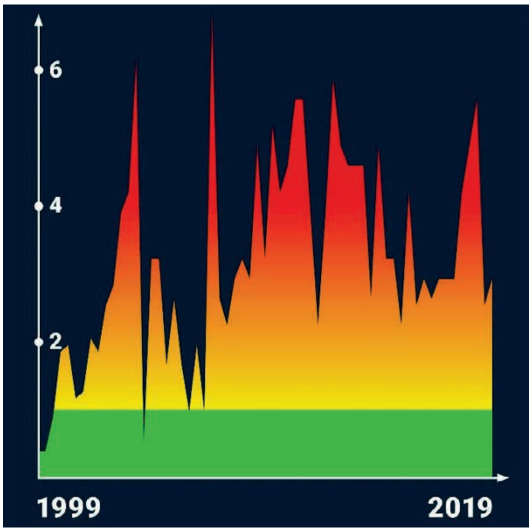


Fig. 3. Average monthly formaldehyde concentrations in the air of Kyiv, in multiplicity with the daily average maximum permissible concentrations (MPC), June–August 1999–2019
Vertical axis: exceeding the MPC. Horizontal axis – years. Source of data: LUN Misto, 2019b

Ryc. 3. Średnie miesięczne stężenia formaldehydu w powietrzu Kijowa, w wielokrotności do średnich dziennych maksymalnych dopuszczalnych stężeń (MPC), czerwiec–sierpień 1999–2019
Oś pionowa: przekroczenie MPC. Oś pozioma – lata. Źródło danych: LUN Misto, 2019b

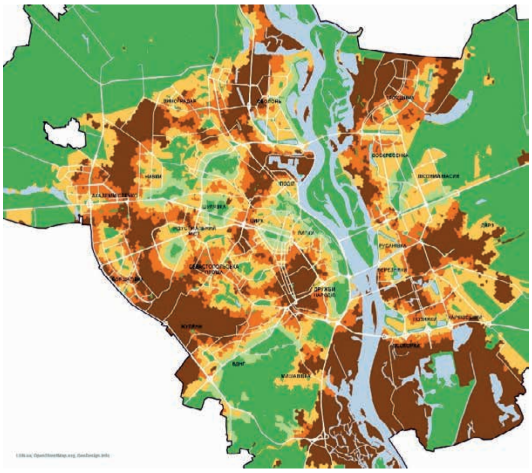


Fig. 4. Pedestrian accessibility analysis of green area availability in Kyiv. Source of data: LUN Misto 2019a

Ryc. 4. Analiza dostępności terenów zielonych dla pieszych w Kijowie. Źródło danych: LUN Misto, 2019a

PM10 (14%) and SO_2 (7%). Currie and Bass (2005) established that 109 ha of green roofs retained 7.87 metric tons of air pollutants.

Today, in close cooperation with scientists of different universities and building companies of Ukraine the community began to form a library of data on the assessment of environmental indicators in Kyiv and their influence on city residents; all results are posted on the platform https://misto.lun.ua/. The official monitoring of atmospheric air pollution in Kyiv and Kyiv region carry out the Central Geophysical Observatory, which includes 16 posts in different districts and checks 20 pollutants in the air. According official data the formaldehyde concentration is higher than limit values for last years in Kyiv (Fig. 3). Found that the average monthly formaldehyde concentration in Kyiv air was in the range of the limits (0.4 MPC) in June 1999. More than 10 years since August 2006 the limit values exceeded in the air and in July 2019 the parameter MPC excessed in 3 times (LUN Misto 2019b).

The availability of green spaces and walking accessibility are an integral indicator of well-being outcomes in the city. Nearly 35.3% Kyiv districts have not green area and live there 18.9% citizens (Fig. 4). 25.8% citizens of Kyiv live in districts with satisfactory green area and this territory covers 8% of the city. Accordingly, 45.3% citizens live with good green areas (48.5% Kyiv area). Finally, with the best values of green spaces live 10% citizens of Kyiv and occupies this territory 8.2% of the city (LUN Misto 2019a). Implementation green roofs in the system of greenery can offset poor green space in the city.

Consequently, the environmental situation in Kyiv proves the urgent need for searching modern approaches in greening, taking into account urban problems.

In 2016 was introduced first intensive roof in Kyiv RC "Royal Tower" (Fig. 5) where all landscape works made landscape company L-Design. The project was so successful that in 2017 the company developed the next RC "Smart Plaza Polytech" (Fig. 6). L-design architects create and implement landscape designs for park gardens, public recreational areas and outdoor spaces in urbanized and suburban environments nearly 15 years in Ukraine.

In 2016 for creation of RC "Royal Tower" green roof Zinco Ukraine offered for landscape company several systems with different prices: traditional construction for 122.99 euro/m², cold roof B1–156.40 euro/m², cold roof B2–144, 26 euro/m² and cold roof pass B3–128.94 euro/m². In both cases, RC "Royal Tower" and RC "Smart Plaza Polytech" builder chose traditional construction – Garden on the roof.

In addition, Zinco Ukraine in 2019 launched sales of the first handler in Ukraine for designing green roofs and brochures about green roof systems that created for Ukrainian landscape designers that can be found on the official website promo version http://www.zinco.com.ua/brochure to better understand green roof construction.

PROJECT INFORMATION RC "ROYAL TOWER" (KYIV)

Object	ROYAL TOWER
Area	700 m^2
Year	2016
Projector	TARYAN Group, Poznyakizhilbud JSC
Builder	TARYAN Group, Poznyakizhilbud JSC
Landscape works	L-Design (landscape architecture – Svitlana Smiian)
Construction works	L-Design
System	Zinco, Garden on the roof

The concept of the roof terrace of the LC "Royal Tower" was developed by British landscape architect John Dawes and landscape design – landscape company L-Design. The residential building is more than 100 m high and has 31 floors. The plant range includes 29 species of ornamental plants, including 16 trees and 13 shrubs. The main idea of the green roof was the formation of green areas in the islands of the terrace.

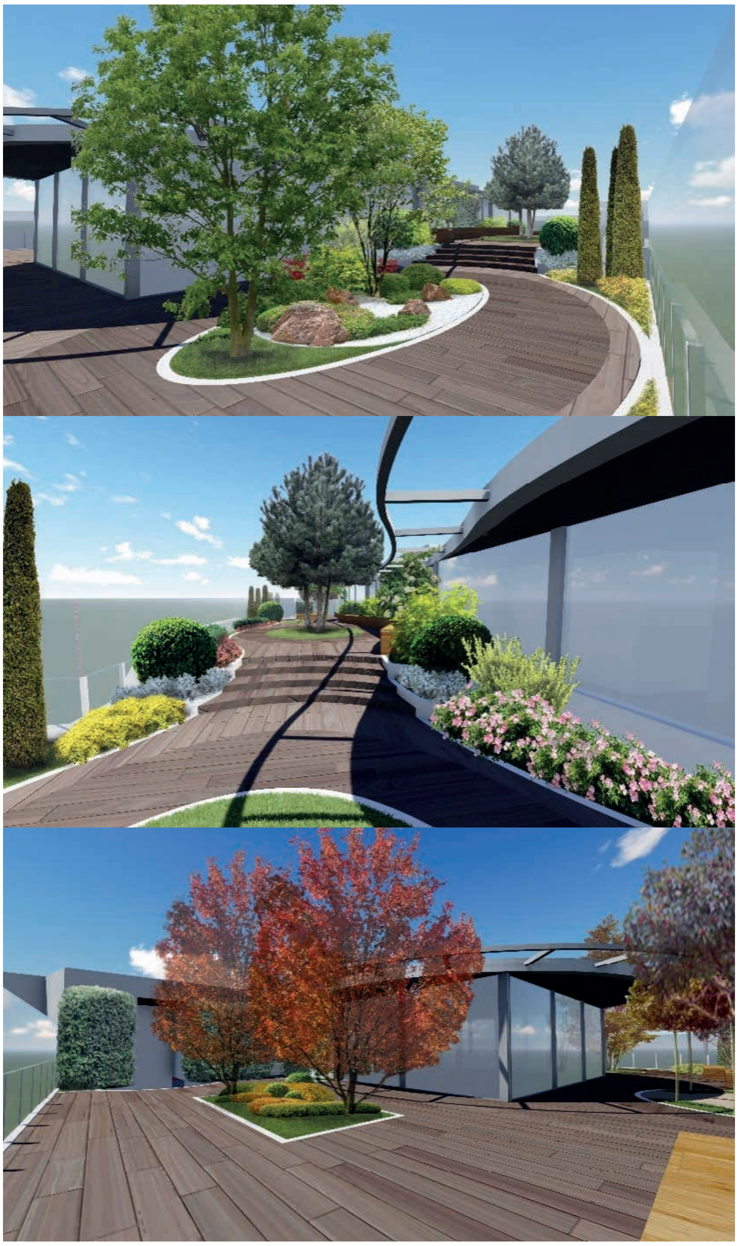


Fig. 5. 3-D projects of intensive roof LC "Royal Tower" (Source: L-Design, 2016)

Ryc. 5. 3-D projekt intensywnego dachu KM "Royal Tower" (Źródło: L-Design, 2016)

PLANT ASSORTMENT

Coniferous trees
1. *Thuja occidentalis* 'Smaragd'
2. *Thuja occidentalis* 'Brabant'

Coniferous shrubs
3. *Pinus mugo* 'Mugo mughus'
4. *Pinus mugo* 'Pumilo'
5. *Thuja occidentalis* 'Danica'
6. *Taxus baccata* 'Repandens'

Deciduous trees
7. *Quercus palustris*
8. *Quercus rubra*
9. *Malus* 'Royalty'
10. *Carpinus betulus* 'Fastigiata'
11. *Pinus sylvestris*
12. *Amelanchier lamarckii* 'Schirmform'
13. *Acer* 'Globosum'
14. *Acer rubrum* 'Red Sunset'
15. *Acer rubrum* 'Autumn Flame'

Deciduous shrubs
16. *Ligustrum vulgare* 'Atrovirens'
17. *Spirea* 'Little Princess'
19 *Spirea* 'Golden Princess'
20. *Spirea* 'Golden Flame'
21. *Euonymus alatus*
22. *Hydrangea arborences* 'Anabelle'
23. *Hydrangea petiolaris*
24. *Berberis thunbergii* 'Bagatelle'
25. *Berberis thunbergii* 'Golden Rocket'
26. *Parthenocissus Veitchii*
27. *Physocarpus* 'Dart s Gold'
28. *Rosa*
29. *Azalea Jap.* 'Marushka'

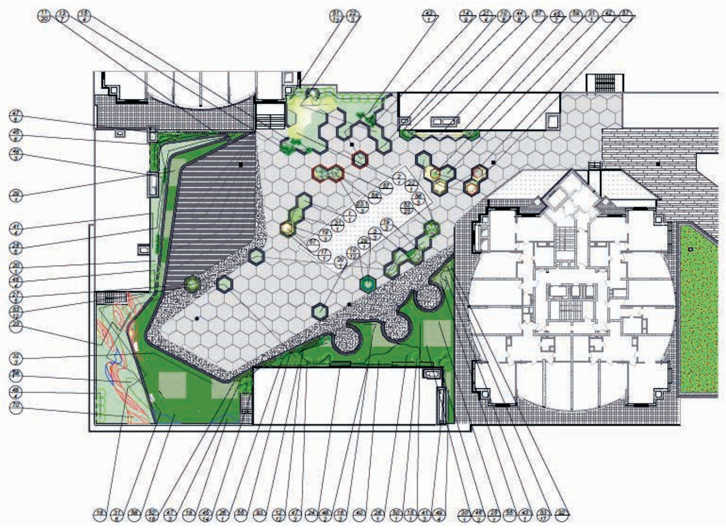


Fig. 6. Dendrology plan RC "Smart Plaza Polytech" (Source: L-Design, 2017)

Ryc. 6. Plan dendrologii KM "Smart Plaza Polytech" (Źródło: L-Design, 2017)

PLANT ASSORTMENT

Coniferous trees
1 *Abies concolor*
2 *Pinus sylvestris*
3 *Thuja occidentalis* 'Smaragd'

Coniferous shrubs
4 *Juniperus horizontalis* 'Andorra Compact'
5 *Juniperus horizontalis* 'Willtoni'
6 *Juniperus* 'Glauca'
21 *Acer rubrum* 'Red Sunset'
22 *Magnolia lilieflora* 'Susan'
23 *Prunus* 'Pissardi'
24 *Malus* 'Umbrella'
25 *Malus* 'Makowieckiana'
26 *Prunus maakii*

Deciduous trees
14 *Cercic canadensis*
15 *Betula papyrifera*
16 *Ligustrum vulgare* 'Atrovirens'
17 *Carpinus betulus*
18 *Quercus palustris*
19 *Quercus robur* 'Fastigiata Koster'
20 Amelanchier lamarckii 'Schirmform'

Perennial herbs
47 *Allium* 'Gladiator'
48 *Veronicastrum virginicum* 'Blue'
49 *Geranium sanguineum*
50 *Polygonum amplexicaule*
51 *Nepeta faassenii* 'Six Hills Giant'
52 *Sanguisorba tenuifolia*
53 *Lavandula angustifolia*
54 *Alchemilla mollis*
55 *Stachys byzantina*

Cereals
56 *Calamagrostis acutiflora*
57 *Pennisetum alopecuroides*
58 *Arrhenatherum elatius* subsp.bulbosum f.variegatum

Deciduous shrubs
27 *Azalea* Jap. 'Marushka'
28 *Actinidia kolomikta* 'Adam'
29 *Berberis thunbergii* 'Bagatelle'
30 *Euonymus alatus*
31 *Weigela florida*
32 *Parthenocissus Veitchii*
33 *Hydrangea arborences* 'Anabelle'
7 *Juniperus* 'Old gold'
8 *Juniperus* 'Tamariscifolia'
9 *Pinus mugo* 'Mugo mughus'
10 *Pinus mugo* 'Pumilo'
11 *Pinus sylvestris* 'Watereri'
12 *Taxus baccata* 'Repandens'
13 *Thuja occidentalis* 'Danica'
34 *Hydrangea paniculata*
35 *Hydrangea petiolaris*
36 *Parthenocissus*
37 *Cornus alba* 'Elegantissima'
38 *Cornus sanguinea* 'Midwinter Fire'
39 *Cotoneaster dammeri* 'Coral Beauty'
40 *Cotoneaster dammeri* 'Radicans'
41 *Pachysandra terminalis*
42 *Rosa*
43 *Spiraea cinerea* 'Grefsheim'
44 *Spiraea* 'Golden Princess'
45 *Spiraea* 'Goldflame'
46 *Spiraea* 'Little Princess'

PROJECT INFORMATION RC "SMART PLAZA POLYTECH" (KYIV)

Object	SMART PLAZA
Area	1532 m^2
Year	2017
Builder	UDP
Projector	AVG Group
Construction works	L-Design
Landscape works	L-Design (landscape architecture – Svitlana Smiian)
System	Zinco, Garden on the roof

The residential complex has two buildings with 23 floors, except the residential complex there is a shopping and entertainment center. For creating the intensive roof landscape designer used 58 species of plants: 15 trees (3 coniferous, 12 deciduous), shrubs 29–10 coniferous and 19 deciduous, 9 perennial herbs, 3 species of cereals.

2. Methodology

Research on providing lighting for plants conducted in August 2019 on the territory of RC "Royal Tower" intensive green roof, which locates in the central part of Kyiv, 37-K Saksaganskogo Str. (Fig. 7). The whole territory of garden fenced with 3 m high shockproof glass that makes it possible to protect plants from wind gusts and creates favorable conditions for plant growth and development.

The garden is located in the southeastern part of Kyiv on the low slopes of Pechersk Hills (coordinates 50°32 'north latitude and 30°33' east longitude). Kyiv surroundings characterize by moderate cold continental climate with more or less wet winters. The average annual temperature is 8.0°C. Due the penetration of Atlantic air observed heavy rainfall in the form of wet snow. There are fogs, frosts and ice often. The average temperature in January is -5.0°C, average temperature in July is + 20.2°C. The absolute minimum is -32.9°C; the absolute maximum is +39.4°C. During each month, the average daily air temperature varies widely, but the biggest changes are in the spring months. The average date of the first frost is October 20; the last spring frost in Kyiv was the first half of April (April 12).

Fig. 7. General top view an intensive green roof RC "Royal Tower" (Source: L-Design)

Ryc. 7. Ogólny widok z góry intensywnego zielonego dachu KM "Royal Tower" (Źródło: L-Design)

The latest date of the last freeze is May 27, and the earliest is September 20. The average duration of the frost-free period is 188 days. The average relative humidity for the year is 75%. The continental type of annual rainfall with a maximum in the summer months is characteristic of Kyiv. The average annual rainfall is 641 mm, in some years it varies from 400 to 795 mm. During the active plant growing season falls to 350–400 mm of rain. The highest rainfall occurs in May–July.

Landscape architects use tree crown shape and size as basic component in the formation of architectural composition. For the viewer, the crown shape perceived as a volumetric geometric figure that depends on the branching system of the plant. Besides branching, the visual perception of the density of the crown affected by its size, shape, color and the nature of the arrangement of leaves. We divided trees into three groups by the openness of the crown and the ability to transmit light into the lower horizons: with openwork (up to 80% of light penetrate into the lower crown horizons), semi-openwork (80–50% of light penetrate into the lower crown horizons) and dense crown (less than 50% of light penetrate the lower crown horizons) (Rubtsov 1949). The age of the experimental plants was 15–18 years for deciduous and 25 years – *Pinus pallasiana* D. Don.

We used a spectrometer UPRtek MK350N BASIC to estimate the light regime of crown area (Photo 1). Measurements were obtained for visible spectral wavelength ranges between 380–780 nm from 12.00 to 14.00 in sunny and cloudless, windless weather. One of the most commonly used indices of surface illumination quality is the color-rendering index (CRI). This index allows assessing the ability of artificial light sources to transmit color in comparison with natural light. This index takes values from 1 to 100 (1 – the worst color rendering, 100 – the

Photo 1. Analysis of the light regime with spectrometer UPRtek MK350N BASIC

Fot.1. Analiza reżimu światła za pomocą spektrometru UPRtek MK350N BASIC best). Another parameter of the light characteristic is the color or temperature indicator (CCT), which measured in Kelvin, depends on the type of plant, its age and the state of the crown. In artificial light CCT characterizes the spectral composition of the radiation of a light source. We evaluated such parameters as CRI, CCT, LUX, Delta Ascension, spectrum analysis and measurement of flicker.

For evaluation of winter hardiness and plant vitality, we used plant assortments of intensive roofs RC "Royal Tower" and RC "Smart Plaza Polytech".

An 8-point scale performed the evaluation of winter hardiness visually in 2016–2018 (Sokolov 1957):

- 1 point – winter-hardy plant (without damage);
- 2 points – the ends of shoots of the last year were frozen;
- 3 points – shoots of the last year have been frozen over the whole length;
- 4 points – shoots have become frozen over the last two years;
- 5 points – shoots have become frozen over the last three years;
- 6 points – shoots are frozen to the level of snow cover;
- 7 points – shoots have frozen to the level of the root neck, but the plant has recovered with porosity; 8 points – the plant died of frost.

The plant vitality estimated according to Prokofeva, 2000 methodology 5-point scale:

5 points (excellent) – plant doesn't affected by pests and diseases, there are no dry shoots, retains the shape of the trunk and crown, which is natural for its species, blooms and bears fruit every year; 4 points (good) – the crown has dry shoots, the plant affected by pests, partially preserves the natural the shape of the trunk and crown;

3 points (satisfactory) – the crown has dry shoots, blooms without fruiting, the plant is affected by disease and pests, loses the natural shape of the trunk and crown;

2 points (bad) – there are dry shoots in the crown, the plant affected by diseases and pests, without natural form of the trunk and crown, doesn't bloom and bear fruit;

1 point (dies) – dries aboveground part.

3. Results and discussion

The light for plants is a key factor for growth. Different types of woody plants require different light intensity, so they are divided into light-demanding and shade-resistant, sometimes even semi-shade. The lighting requirements in woody plants change with age and growth conditions. Found that the woody plant at a young age is more shade-resistant than in old age, moreover, the lighting requirements for plants increase after its moving from warmer areas to cooler (Kolesnikov 2018). The shape of the crown of woody plants changes not only with age but also due the influence of environmental factors, such as the deforming effect of wind. The illumination directly affects the shape of the crown, for example, trees that grow near buildings (in conditions of low light) develop more branches on the illuminated side, which leads to the development of unilateral crown shape.

In the daytime, in the shade of plants, CRI maintains rather high indices from 90–98 (Table 1), and exceeds or is comparable with the characteristics of the best artificial light sources (Fig. 6). CCT reflects the light-absorbing and reflective abilities of the crown in sunlight. These characteristics depend on its thickening and architectonics, the height of a tree or bush, the structure of assimilation organs, the thickness and chemical composition of the cuticle, as well as the composition of plastid and auxiliary pigments. The presence of auxiliary (protective) pigments in the leaves such as carotenoids, anthocyanin and some others significantly affect the selective absorption capacity of plants. The predominance of anthocyanin or other substances of phenolic nature in the leaves leads to the active absorption of short-wave radiation by the leaves, which has a damaging effect on plants in case of excessive insolation.

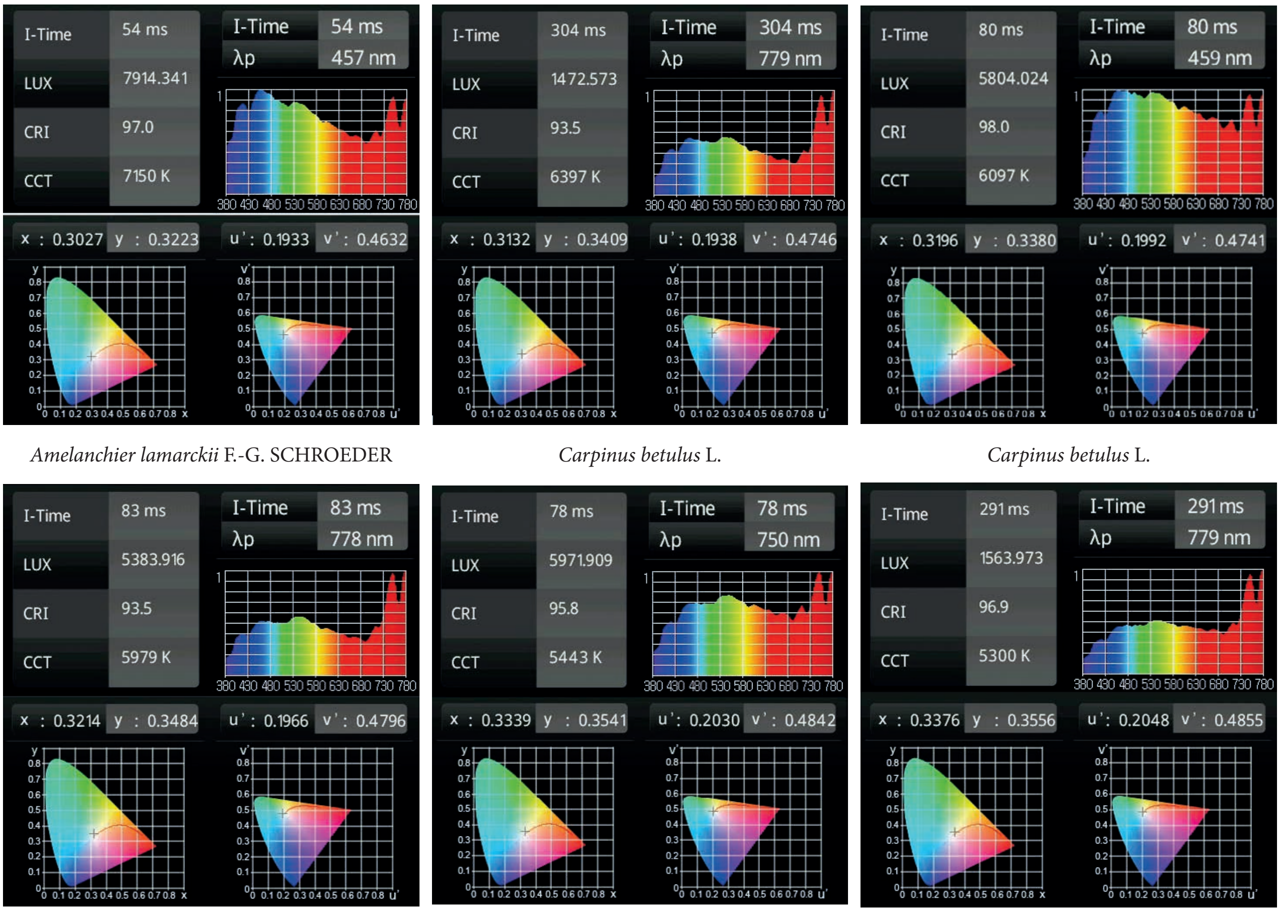
Thus, the *A. lamarckii* crown is quite transparent to electromagnetic radiation and transmits a relatively large number of light blue and blue rays. Under such conditions, the CCT is quite high. The total illumination in the range from 420 to 460 nm is 1.6–6.5 times higher than under the crown of *C. betulus*. In the red spectrum this difference is somewhat reduced and ranges from 1.21 to

Table 1. Illumination indicators for plant species with different types of crown openness (Source: own study)

Tabela 1. Wskaźniki oświetlenia dla gatunków roślin o różnych typach otwarcia korony (Źródło: opracowanie własne)

No.	Latin name	Crown openness *	Parametrs				
			Lux	CRI	CCT	420–460 nm	630–670 nm
2 1.	*Amelanchier lamarckii* F.-G. SCHROEDER	semi-openwork	7914.341	97.0	7150	123.7523	79.25601
	Carpinus betulus L.	dense	3602.181	96.5	7572	59.33727	34.6563
2.	*Carpinus betulus* L.	dense	1472.573	93.5	6397	19.70083	14.60692
2.	*Carpinus betulus* L.	dense	5804.024	98.0	6097	76.91709	65.29127
3.	*Quercus palustris* Muenchh	semi-openwork	5383.916	93.5	5979	66.39591	56.00391
4.	*Acer platanoides* L.	semi-openwork	5971.909	95.8	5443	67.5794	69.83498
5.	*Pinus pallasiana* D.Don	openwork	1563.973	96.9	5300	17.18009	19.06392

* Methodology Rubtsov 1949



Amelanchier lamarckii F.-G. SCHROEDER — *Carpinus betulus* L. — *Carpinus betulus* L.

Quercus palustris Muenchh. — *Acer platanoides* L. — *Pinus pallasiana* D.Don

Fig. 6. Spectrometry of crown light regime plant species

Ryc. 6. Spektrometria koron drzew różnych gatunków roślin

5.4. In order to reduce the illumination (Lux) of the soil under the crown, the studied species are located as follows: *A. lamarckii* > *A. platanoides* > *Q. palustris* > *P. pallasiana* > *C. betulus*.

The ratio of the total illumination in the intervals 420–460 nm and 640–630 nm that are most significant for chlorophylls for *C. betulus* and *A. lamarckii* was the highest. According to the temperature characteristics of the light passing through the crown of these plant species, we can assume a certain growth retardation in plants of the lower tier. The opposite effect expected for *A. platanoides* and *P. pallasiana*. For these species, the indicator of the ratio of total illumination in the photosynthetically important range was less than 1.

Investigated intensive green roofs visualize the formal landscape in the form of a park on the podium and a sufficient amount of soil (30–120 cm) allows to support a large assortment of plants in a highly decorative effect. We identified 29 species in the plant structure of LC "Royal Tower" intensive green roof, where coniferous trees and shrubs (*Thuja occidentalis* 'Smaragd', *Thuja occidentalis* 'Brabant', *Pinus mugo* 'Mugo mughus', *Pinus mugo* 'Pumilo', *Thuja occidentalis* 'Danica', *Taxus baccata* 'Repandens') provide throughout the year decorative effect of composition; the deciduous trees and shrubs (23 species) colorful form, beautifully flowering and fragrant curtains in the spring and summer (Table 2).

Table 2. Vitality and winter hardiness of plants on the LC "Royal Tower" intensive roof (Source: own study)

Tabela 2. Żywotność i zimotrwalość roślin na dachu intensywnym KM "Royal Tower" (Źródło: opracowanie własne)

		Winter hardiness, points	Vitality, points
Coniferous trees			
1.	*Thuja occidentalis* 'Smaragd'	1	5
2.	*Thuja occidentalis* 'Brabant'	1	5
Coniferous shrubs			
3.	*Pinus mugo* 'Mugo mughus'	1	5
4.	*Pinus mugo* 'Pumilo'	1	5
5.	*Thuja occidentalis* 'Danica'	1	5
6.	*Taxus baccata* 'Repandens'	1	5
Deciduous trees			
7.	Quercus palustris	1	5
8.	Quercus rubra	1	5
9.	*Malus* 'Royalty'	1	5
10.	*Carpinus betulus* 'Fastigiata'	1	5
11.	Pinus sylvestris	1	5
12.	*Amelanchier lamarckii* 'Schirmform'	1	5
13.	*Acer* 'Globosum'	1	4 (leaf chlorosis)
14.	*Acer rubrum* 'Red Sunset'	1	5
15.	*Acer rubrum* 'Autumn Flame'	1	5
Deciduous shrubs			
16.	*Ligustrum vulgare* 'Atrovirens'	1	5
17.	*Spirea* 'Little Princess'	1	5
19.	*Spirea* 'Golden Princess'	1	5
20.	*Spirea* 'Golden Flame'	1	5
21.	Euonymus alatus	1	5
22.	*Hydrangea arborences* 'Anabelle'	1	5
23.	Hydrangea petiolaris	2	5
24.	*Berberis thunbergii* 'Bagatelle'	1	5
25.	*Berberis thunbergii* 'Golden Rocket'	1	5
26.	Parthenocissus Veitchii	1	5
27.	*Physocarpus* 'Dart s Gold'	1	5
28.	Rosa	2	4 (leaf spot)
29.	*Azalea Jap.* 'Marushka'	2	4 (leaf chlorosis)

It should be noted that in addition to the decorative function of plants on LC “Royal Tower” green roof they perform such important functions as providing a forage base for wild bees and beneficial insects (*Spirea* ‘Little Princess’, *Spirea* ‘Golden Princess’, *Spirea* ‘Golden Flame’, *Hydrangea arborences* ‘Anabelle’, *Hydrangea petiolaris, Berberis thunbergii* ‘Bagatelle’, *Berberis thunbergii* ‘Golden Rocket’, *Parthenocissus Veitchii, Physocarpus* ‘Dart s Gold’, *Rosa,Azalea jap.* ‘Marushka’), and fruits such plants as *Amelanchier lamarckii* ‘Schirmform’ and *Malus* ‘Royalty’ can be used for food. Evaluation of vitality and winter hardiness of plant assortment on the green roof LC “Royal Tower” show that most species characterize by high vitality and successful cultivate on green roofs in Kyiv. Only *Azalea* Jap. ‘Marushka’, *Hydrangea arborences* ‘Anabelle’ and *Rosa* cultivars had slight leaves damage.

The species composition of plants on the green roof LC “Smart Plaza Polytech” compared to the green roof LC “Royal Tower” is much larger (58 species) where the basis of the compositions consists from coniferous (3 species) and deciduous (12 species) trees. The special beauty and expressiveness of compositions for the year create 10 coniferous species and 19 deciduous species shrubs, perennial herbs (9 species) and cereals (3 species). Cereals are bright accents in the spring-summer and winter periods. Due to the combination of plants with different flowering period created the effect of continuous and long flowering that in turn contributes to the formation of the necessary forage for birds, the maintenance of the vitality of populations of wild bees and wasps, beneficial insects. All plants characterized by high vitality and decorative effect, only two representatives – *Azalea* Jap. ‘Marushka’ and *Hydrangea arborences* ‘Anabelle’ on external features such as chlorosisas resulting from the lack of certain nutrients (Table 3).

For renovation of vitality and decorative effect of plants made fertilization by specialized mineral fertilizers.

4. Conclusion

The global ecological crisis and rapid reduction of green areas due to urban growth and building activity provide impulses for landscapers to search new solutions and concepts in urban landscape design. The main priority in urban design should be bioclimatic urbanism that allows to efficient use of urban territories: conserve resources (energy, heat etc.), neutralize the impact of anthropogenic factors and create well-being conditions for citizens.

Global climate change and the rapid increase of urban population require searching the environmentally friendly measures in areas with high anthropogenic load. The market of green roofs in Ukraine is only develop, at the same time, in Europe and America; it is working on a well-established scheme. Lack of laws and priorities for implementation of green roofs in Ukraine suspends development of green industry. World practice shows that encouraging people can implement green roofs under conditions of state support. Formed green roofs in Kyiv are private or restricted access. After comparison of the illumination regime under the crowns of trees with the rank classification of the openwork of their crowns, we found the validity of this approach, which can be used for creation of compositional solutions for the selection of complementary plant species taking into account their exactingness to the qualitative characteristics of light energy. Unclear is the question of high shading under the crown of *P. pallasiana* which characterized by openwork crown according to Rubtsov’s classification. For greening intensive green roofs, it is necessary to conduct research about the amplitude of the basic requirements of plant growing conditions. The results of winter hardiness and vitality evaluation of plants growing on intensive roofs demonstrate high rates due controlled growth conditions and lower anthropogenic load. Studies of the ecological nature of the plant growth on intensive roofs need to be continued and improved, as many issues remain to be explored.

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References

Adams S., Marriott D., 2008. Cost Benefit Evaluation of Ecoroofs. City of Portland, Portland, OR, USA, 12.

Bastin J.F., Clark E., Elliott T., Hart S., van den Hoogen J., Hordijk I., Ma H., Majumder S., Manoli G., Maschler J., Mo L., Routh D., Yu K., Zohner C.M., Crowther T.W., 2019. Correction: Understanding climate change from a global analysis of city analogues. PLOS ONE 14(10): e0224120. https://doi.org/10.1371/journal.pone.0224120

City of Toronto. Report on the Environmental Benefits and Costs of Green Roof Technology for City of Toronto, 2005. Ryerson University, Toronto, ON, Canada.

Currie B.A., Bass B., 2005. Estimate of air pollution mitigation with green plants and green roofs using the UFORE model [in:] Proceedings of Third Annual Greening Rooftops for Sustainable Communities Conference, Awards and Trade show, Washington, DC, May 4–6.

Dunnett N., Kingsbury N., 2004. Planting Green Roofs and Living Walls. Timber Press, Portland.

Eunha S., Heungsoon K., 2019. Benefit-Cost Analysis of Green Roof Initiative Projects: The Case of Jung-gu, Seoul. J. MDPI Sustainability, 11, 3319; doi: 10.3390/su11123319

Hui S.C.M., 2011. Technical Guidelines for Green Roofs Systems in Hong Kong. The University of Hong Kong, Hong Kong, China.

Kolesnykov A.Y., 2018. Dekoratyvnaia dendrolohyia. Pereyzdanye. Kharkov: Zolotye stranytsy, 676.

Korea Forest Service, 2011. A Guideline for Developing Urban Forest Sustainability Index; Korea Forest Service. Daejeon, South Korea. [In Korean].

LUN Misto, 2019a. De v Kyievi naibilshe parkiv i skveriv [on-line]. Available: https://misto.lun.ua/formaldehyde.

LUN Misto, 2019b. Yak zminylosia povitria Kyieva za 20 rokiv [on-line]. Available: https://misto.lun.ua/ozelenennya

Nurmi V., Votsis A., Perrels A., Lehvävirta S., 2013. Cost-Benefit Analysis of Green Roofs in Urban Areas: Case Study in Helsinki; Finnish Meteorological Institute, Helsinki, Finland. http://hdl.handle.net/ 10138/40150 [25.01.2019].

Prokofeva E.A., 2000. Nekotorye aspekty ekoloho-byolohycheskoho sostoianyia dereviev Alupkynskoho parka. Sovremennые nauchnые yssledovanyia v sadovodstve. Ch. 1, S. 109–111 [In Russian].

Rubtsov L.I., 1949. Roslyny u landshaftnii arkhitekturi. Akademiia Arkhiektury Ukrainskoi RSR, Kyiv [In Russian].

Scharf B., Kraus F., 2019. Green Roofs and Greenpass., MDPI, Buildings 9, 205. doi: 10.3390/buildings9090205

Sokolov, S.Ya., 1957. Sovremennoe sostoianye teoryy akklymatyzatsyy y yntroduktsyy rastenyi. Yntroduktsyia rastenyi y zelenoe stroytelstvo. M.: Selkhozyzdat, 1957. Vyp. 6., S. 34–42. [In Russian].

State of Victoria. Growing Green Guide: A Guide to Green Roofs, Walls and Facades in Melbourne and Victoria,Australia; State of Victoria: Melbourne, Australia, 2014.

State Statistics Service of Ukraine. https://ukrstat.org/en [10.01.2019].

Tkachenko T., Mileikovskyi V., Ujma A., 2019. Field Study of Air Quality Improvement by a "Green Roof" in Kyiv. System Safety: Human – Technical Facility – Environment, 1(1), 419–424. doi: https://doi.org/10.2478/czoto-2019–0054

Tumini I., 2014. The urban microclimate in open space. Case studies in Madrid, Cuad. Investig. Urbanistica. 96, 78.

UNFPA ANNUAL REPORT, 2007. https://www.unfpa.org/sites/default/files/pub-pdf/ar07_eng.pdf [10.01.2019].

United Nations. Transforming Our World: The 2030 Agenda for Sustainable Development; A/RES/70/1, 2015 United Nations, New York, USA.

World Health Organization (WHO), 2002. The World Health Report 2002. Reducing Risks, Promoting Healthy Life. WHO, Geneva.

Yang J., Yu Q., Gong P., 2008. Quantifying air pollution removal by green roofs in Chicago. doi: 10.1016/j.atmosenv.2008.07.003

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Chinese cities extensive and semi-intensive green roofs

Ekstensywne i półintensywne dachy zielone w chińskich miastach

Abstract

The subject of the work is the analysis of eight examples of green roofs from three selected cities of China, like: Changsha, Hangzhou and Shanghai. Showing diversity in the design of roofs and in the selection of materials such as natural plants or artificial grass. For the analysis there were selected seven examples of green roofs created on public buildings and one example of a private buildings complex with artificial materials only which were used. Another aim was to match and select the functions that individual roofs fulfill and to mention about the benefits of designing gardens on the roofs.

Materials for work were collected during the stay in selected cities. For the purposes of the comparative analysis, taken into account such features as the area they occupy, the type of roof and slope, the type of building (private, public), type of roof (extensive, semi-intensive, artificial) and vegetation used.

Streszczenie

Przedmiotem pracy jest analiza ośmiu przykładów zielonych dachów z trzech wybranych miast Chin: Changsha, Hangzhou i Shanghai, ukazanie różnorodności w projektowaniu i zastosowaniu dachów oraz w doborze materiałów takich jak żywe rośliny lub sztuczna trawa. Przeanalizowano siedem przypadków zielonych dachów stworzonych na budynkach publicznych i kompleks budynków prywatnych, do których wykorzystane zostały wyłącznie sztuczne materiały. Kolejnym celem było dopasowanie i wyselekcjonowanie funkcji, jakie spełniają poszczególne dachy oraz wymienienie korzyści wynikających z projektowania ogrodów na dachach.

Materiały do pracy zebrano podczas pobytu w wybranych miastach. Do analizy porównawczej wzięto pod uwagę takie cechy jak powierzchnia, jaką zajmują, rodzaj dachu i nachylenie, typ budynku (prywatny, publiczny), rodzaj dachu (ekstensywny, półintensywny, sztuczny) oraz zastosowaną roślinność.

Key words: China, ecology, biodiversity, design, alternative forms of greenery, building
Słowa kluczowe: Chiny, ekologia, bioróżnorodność, projektowanie, alternatywne formy zieleni, budynek

1. Introduction

Green roofs are often assumed for reasons of aesthetic nature, but nowadays should be treated primarily as an economic investment, which will not only bring a return on investment, but they give long term of material benefits (Francis and Jensen 2017; Oberndorfer et al. 2007).

As we may know green roofs have been established for over one hundred years and they have become one of the main design idea in urban area in the past decades. Many scientific researches focus on its advantages, like cooling possibilities, efficiency and survival rates of plants and also advantages.

Vegetation is the key element and the most important thing in installing green roofs. It also provides some factors in choosing suitable plants on rooftops, factors including species that are drought tolerant, solar radiation tolerant, and cooling ability of plants, they clean the air pollution and are suitable for urban conditions. In addition, green roofs play a critical role in improving the urban environment. They perfectly enriching the biodiversity, delaying the storm peak to the drainage system, diminishing the runoff quantity, purifying the air pollutants as well as the runoff quality (Baik et al. 2012; Cook-Patton and Bauerle 2012; Madre et al. 2014, Speak et al. 2012; Versini et al. 2016).

2. Overview of the literature

Factors that green roofs should fulfill are: a) Aesthetic aspects: improve the aesthetics of the city; they eliminate the feeling of overwhelming caused by the surrounding high buildings; masking imperfections of the building in order to obtain a better visual effect; raising the rank and value of the area, b) Nature aspects: they filter and purify the air from settling dust, smoke or soot; reduce the amount of harmful chemical compounds, pollen and gases; they purify and retain rainwater; increase air humidity; reduce the temperature in the city; reduce the so-called phenomenon "Urban Heat Island" (UHI) (Wong et al. 2009); reduce the amount of smog; increase biodiversity in urban areas, c) Economic aspects: reduce the energy consumption in the building; reduce the costs of air conditioning; they prevent buildings from getting cold for the winter and heating in the summer, which reduces the expenses related to the installation of heating and cooling devices and the purchase of energy; extend the service life of materials used to build the roof; reduce the risk of repairs to the roof structure; suppress noise, d) Social aspects: they eliminate stress and aggression; they soothe the senses; they fulfill educational functions.

In the case of the environmental aspect, environmental benefits are the most frequently cited reasons for creating living green roofs. According to the literature, in the process of photosynthesis, the area of 155 m^2 of green space produces enough O_2 for one person per day (Kania et al. 2013; Voelz 2016). Each green surface is also an air purifying filter, dirt settles on the leaves, needles and then together with atmospheric precipitation they are rinsed to the ground. Gaseous pollutants are also absorbed by vegetation. Annually, the green roof absorbs about 10 to 20% of dust and harmful gases from the air. Air purification in cities is determined not only by horizontal but also vertical form of greenery. Therefore, the ideal solution for urbanized areas are green roofs and vertical gardens, set on the walls of buildings. The use of appropriate plant species allows for the reduction of such compounds as: NO_2, SO_2, CO_2. In contrast, the cultivated vertical garden with an area of around 10 m^2 absorbs the same amount of CO_2 per year as a four-meter tree (Hopkins 2011).

Green roofs are also an additional surface absorbing rainwater, which reduces the risk of flooding in cities. Vegetation on roofs can keep 15 to 90% of rainwater from one rainfall in a given place (Kania et al. 2013).

In cities, roof surfaces and facades can easily heat up and then give back heat to the atmosphere. The surface temperature of roofs with normal coverage can reach up to 60°C. The resulting "urban heat island" contributes to the rise of temperature in the city. Consequently, the temperature in cities can be higher by 8 to 10°C (Davidson 1998). In the summer, green roofs do not heat up like roofs with traditional cover, while in winter they reduce heat losses. The surface temperature of the green roof depends on various types of vegetation (Velazquez 2005).

Another role of green roofs is to increase biodiversity in highly urbanized areas. Depending on the height of the green roofs, insects and birds visit them. According to the literature, in search of food or rest birds can rise to the height of the 19th floor, and butterflies to the height of even 20 floors (Velazquez 2005).

Regarding the economic aspect, one of the main benefits resulting from the installation of green roofs and living walls is the reduction of energy consumption in the building, thanks to the shading and insulating properties of the plant layer. The greening of roofs and facades of buildings allows for reduction of air conditioning costs in the range of 17–79% per annum and 0.6–19.5% in the total settlement of energy consumption in a building (Kania et al. 2013). Proszę zamienić to zdanie na: Implementation of the green roof allows the temperature to be reduced on avarage by 2–5°C in the rooms below it (Harazono 1990/1991; Kumar and Kaushik 2005). During the winter, the design of the living garden on the wall protects the facade from the effects of wind, by reducing energy consumption for heating. In rooms with green walls, the temperature is reduced by an average of 5°C, which significantly reduces energy consumption for cooling by means of air conditioning (Chen 2002). A 20 cm layer of soil substrate and 20–40 cm of plant cover has the same insulating properties as 15 cm of mineral wool.

Introducing greenery in densely built-up areas is also important from the point of view of the mental health of a human being. Greenery eliminates stress, soothes the senses and reduces the high level of aggression. In turn, emotional balance affects the productivity of employees, which is why green roofs and living walls are increasingly used in office buildings where people work. It should be remembered that during the design process, it is necessary to take into account the fact that they are visible from the window and available as resting places. Equally popular is the use of green roofs and vertical gardens in the urban public space, such as shopping centers. They function as a magnet attracting customers, creating an integration space. Green roofs can perform educational functions, making the average users aware of the benefits of using such solutions (Velazquez 2005).

3. Research method

A research method is based on a multi-criterion case study and comparative analysis of 7 different aspects forming green roofs. In this paper, the potential assessment process includes three steps: the spatial recognition of green roofs types, roof technical analysis and potential verification. The first step is to divide different green roofs according to type: artificial, extensive or semi-intensive. The second stage involves analyzing and assessing the technical aspects of roofs. The final step is showing the roof potential in terms of nature aspects: enlarging biologically active surfaces, creating new habitats, filtering and purifying the air from settling dust, smoke or soot, reducing the temperature in the city; in terms of economic functions such as reduce the energy consumption in the building; and a last in terms of aesthetic and also social aspects. The detailed process is shown in Fig. 1.

The roofs that have been chosen for work are mainly extensive roofs. However, mostly artificial. In addition, several examples

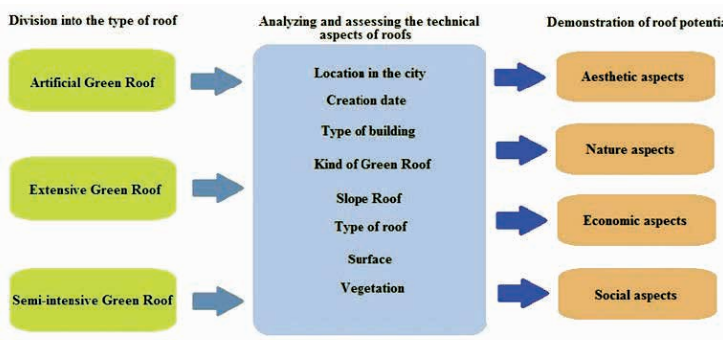

Fig. 1. Evaluation process of roof greening potential (Source: own study)

Ryc. 1. Proces oceny potencjału zazieleniania dachu (Źródło: opracowanie własne)

Fig. 2. Map of China (Source: own study on base solutions4development.com)

Ryc. 2. Mapa Chin (Źródło: opracowanie własne na podstawie solutions4development.com)

of semi-intensive roofs were also included in the thesis, due to the small number of available extensive roofs, the scope of the study was extended to include both. And as a last example: a roof designed and built on the building of the University Library on the campus of Hunan Agricultural University. Due to the fact that it was possible to participate in almost all construction stages, the library roof was described in detail. All described roofs were created after 2010, probably the oldest one is the roof of Hangzhou (Fig. 2).

All examples have been described and analyzed in the table. The table has been divided into 10 columns, and 9 are rows, there are elements in the columns that were highlighted in the description of selected examples of green roofs, and the rows contain specific locations and necessary information. In addition, four aspects have been defined which should meet extensive green roofs, they are: aesthetic aspect, natural aspect, ecological aspect and social aspect.

In the analyzed examples, the following was taken into account: address, location, date of building creation and completion of the roof (approximately or determined by decades, due to unavailability of information), type of building on which the green roof was created (whether it is private, whether it is a public building, open to visitors, and what function it has), roof type (extensive, semi-intensive, artificial extensively, artificial half-intensive), roof slope (approximate slope, given in percentage, in the case of a roof with different slopes, the cross-section is shown, i.e. the smallest possible and the largest possible slope, due to the lack of information), roof type (flat roof, domed roof, sloping roof), roof surface (approximate measure, due to the unavailability of information), types of plantings (artificial or natural grass, shrubs, trees, perennials, vegetables, due to the unavailability of information). Because of the difficult or impossible access to some information, the view is subjective sometimes, defined in general or with a wide margin. In addition, another aspect that has been analyzed is to meet the conditions that characterize an extensive green roofs, which are necessary to determine whether a particular roof is full-fledged and functional. The roofs in the table have been cataloged by cities. The text describes them in detail, however, the completely artificial roof is treated separately. Therefore, the order of roofs in the table is different than in the described text.

Problems encountered during the implementation of the task were: lack of access to realized green roof projects (because were located on private buildings, on guarded estates), lack of project documentation and their accessibility, communication problems between Polish students and creating green roofs design companies (an obstacle being the language of communication – English, Chinese), problems with the availability of information on construction dates, land area, roof slope, used plant species (only Chinese plants names, no Latin), information about projects in Chinese only, no translations into English, artificial building green roofs, lined only with imitation grass or artificial grass from the roll. The search area for roofs was enlarged, moved beyond the boundaries of the city of Changsha to the east of China.

Table 1. Roof characteristics (Source: own study)

Tabela 1. Charakterystyka dachów (Źródło: opracowanie własne)

Table with 8 examples of green roofs from China (table designed by M. Weber-Siwirska)

No.	City	Location in the city	Creation date	Type of building	Kind of green roof	Slope roof (%)	Type of roof	Surface	Vegetation
1.	Changsha	Changsha Concert Hall, Binjiang Cultural Park, Xinhe Sanjiaozhou, Kaifu District Changsha, China	2015	Public building, Concert Hall	Artificial extensive, semi--intensive	30<60%	Sloping roof	Around 3200 m^2	Artificial grass and natural shrubs
2. *	Changsha	Empty buildings Binhe Lu, Furong Qu, Changsha Shi	2016	Private 12 buildings, Office for design company	Artificial extensive	30<60%	Domed roof	Around 9000 m^2	Artificial grass
3. **	Changsha	Hunan Agricultural University, 1 Nongda Rd, Furong Qu, Changsha Shi, Hunan Sheng, China	2017	Public building, library,	Extensive, semi--intensive	2<5%	Flat roof	Around 320 m^2	Natural grass, shrubs, trees, plants, vegetables
4.	Hangzhou	Hangzhou underground descent, Nanshan Road	2010-2017	Public space, underground descent	Semi-intensive	5<60%	Domed roof	Around 200 m^2	Natural grass, shrubs
5.	Shanghai	Shanghai Natural History Museum, 510 Beijing W Rd, Jingan Qu, Shanghai Shi, China, 200000	2015	Public building, Museum	Extensive	30<60%	Sloping roof	Around 5600 m^2	Natural grass, shrubs
6.	Shanghai	Shanghai Botanical Garden, Tropicarium, 997 Longwu Rd, Xuhui Qu, Shanghai Shi, China	nd	Public building, tropicarium	Extensive, semi--intensive	10<60%	Sloping roof, domed roof	Around 1500 m^2	Natural grass, roses shrubs
7.	Shanghai	Shanghai Botanical Garden, Gate 3, 997 Longwu Rd, Xuhui Qu, Shanghai Shi, China	nd	Public building, gates	Extensive	10<60%	Sloping roof, domed roof	Around 120 m^2	Natural grass, shrubs
8.	Shanghai	Shanghai Botanical Garden, Main Gate, 997 Longwu Rd, Xuhui Qu, Shanghai Shi, China	nd	Public building, gates	Extensive	5<60%	Sloping roof, domed roof	Around 2000 m^2	Natural grass

* Completely artificial green roof
** Garden analysed in a separate chapter

Photo 1. Main entry to building of the Concert Hall in Changsha (Author's collection)

Fot. 1. Główne wejście do budynku Sali Koncertowej w Changsha (zbiory autora)

Photo 2. Part of the facade of the Concert Hall (Author's collection)

Fot. 2. Fragment fasady Sali Koncertowej (zbiory autora)

Photo 3. View on underground descent, Hangzhou (Author's collection)

Fot. 3. Widok na podziemne zejście, Hangzhou (zbiory autora)

3.1. Characteristics and overview of the analyzed roofs

3.1.1. Changsha Concert Hall, Binjiang Cultural Park

Changsha Concert Hallis located on the Xinhe Delta. Concert Hall was opened to the public on 28th December 2015, and it was designed to be one of the finest music halls in South and Central China. It covering an area of 27,600 m^2 (www.enghunan.gov.cn).

It is a public building with an artificial, extensive green roof, located on a very large area, occupying about 80% of the entire roof area. The roof is in a stepped, sloping form with a large inclination of 30–60%. Lined in one, the highest part with artificial grass from the roll, while the stairs with live shrubs. Each step (Photos 1 and 2) is a kind of wide pot, with a dozen centimeters layer of soil in which the privet (*Ligustrum vulgare*) grows. The condition of the sown plants is satisfactory. The roof area occupies about 3200 m^2. For the sake of artificial turf, it does not fulfill the natural and economic function, but due to its high attractiveness (Photos 1 and 2), it gives the place a lot of aesthetic value, raises the prestige of the building, attracts residents and tourists, harmonizes well with the surroundings.

3.1.2. Hangzhou underground descent, Nanshan Road

Hangzhou is a big city, which is the capital of Zhegiang province. Hangzhou is the southern part of the ancient Grand Canal waterway, which comes from Beijing.

It is a roof located above the entrance to the underpass located near the lake, at Nanshan Road. The year of construction can be estimated for the period 2010–2017, there is no information on the exact date of the underground passage, which is why the present decade is approximate. As a public area, located on large communication routes, it is entirely open to tourists and walkers. In addition to the underground entrance, it is also possible to enter the roof itself. Between the bushes there are stairs that you could climb to the top. This object is one of the better examples of a half-intense roof. It combines small vegetation with larger bushes. Due to the sloping and rounded construction, the slope of the roof ranged from 5–60%, while the area itself, planted, was estimated at approximately 200 m^2. In the roof there are visible holes for growing trunks and branches of trees (Photo 3).

The roof over the passage fulfills a natural, and in a sense, economic, function for the sake of noise suppression, but above all it fulfills the aesthetic and social aspect. Ideally masks unattractive passage (Photo 4), fits into the surroundings of the lake and all gardens. It gives the historical and traditional place a modern character. It interacts very well with the surrounding, already existing nature, by referring to the use of the same plant species. It does not limit the growth of nearby trees, using holes in the roof structure, thanks to which tree trunks have the possibility of growth. It does not limit the availability of light to other plants.

Photo 4. Roof vegetation, Hangzhou (Author's collection)

Fot. 4. Roślinność na dachu, Hangzhou (zbiory autora)

3.1.3. Shanghai Natural History Museum

The history of the Shanghai Natural History Museum has a long history. It goes back to the Xujiahui Museum, which was founded in 1868 by the French Roman Catholic priest Pierre Heude. A new Shanghai Natural History Museum was opened in 1956, with the collections of Zhendan Museum. In 2001 museum was connected with the Shanghai Science and Technology Museum. The project work of creating a new Shanghai Natural History Museum started on 26th June 2009, and the new Museum opened to the public in the second quarter of 2015 (www.snhm.org.).

Photo 5. Detail of the green roof on a Natural History Museum, Shanghai (Author's collection)

Fot. 5. Detal zielonego dachu w Muzeum Historii Naturalnej w Szanghaju (zbiory autora)

The whole roof is covered with turf and shrubs. In addition, it is lined with CDs right next to the ground (Photo 5), it has a decorative character, as well as aluminum sculptures, placed in groups every few meters. The roof is sloping with an approximate slope of 30 to 60%. The total area is huge, it is set at around 5,600 m^2.

Photo 6. Green roof on a Natural History Museum, Shanghai (Author's collection)

Fot. 6. Zielony dach na Muzeum Historii Naturalnej w Szanghaju (zbiory autora)

The roof fulfills spatial functions, giving a high value to the entire structure, perfectly incorporates the geometrical form of the facade into the surroundings, harmonises with nature and buildings. It meets the natural aspect through the use of live plant species (Photo 6), it purifies the air, water, reduces the air temperature. All this means that economic aspects are also preserved and implemented, which is important especially for such a huge building that fulfills educational functions.

3.1.4. Shanghai Botanical Garden, Tropicarium

Shanghai Botanical Garden is the biggest botanical garden in China. It has a large collection of thousands of plants, including a lot of rare species. First named Longhua Nursery Garden was established in 1954, in 1974 it turned into Shanghai Botanical Garden and finally was opened to the public in 1978. Now it has an area of 81.86 ha.

A green roof was built above huge cactus greenhouse. It is a combination of an extensive and semi-intensive garden. The slope of the roof varies between 10 and 60%. The date when the roof was created is unknown. It is surrounded by tropicarium glass domes (Photo 7). It is divided into several-meter carpets lined with grass, in which rectangular or triangular areas for rose beds were separated. The shape of the roof is diverse, geometric and broken. Initially, flat, with a slight inclination, then narrows and lifts upwards, which makes the inclination increase. Yellow, pink and red rose bushes were used to plant the rebate. The roof is two-level.

Photo 7. Roses shrubs on the green roof on a Tropicarium in Botanical Garden, Shanghai (Author's collection)

Fot. 7. Krzewy róż na zielonym dachu w Tropikarium w Ogrodzie Botanicznym w Szanghaju (zbiory autora)

Photo 8. View on a Gate no. 3 in Botanical Garden, Shanghai (Author's collection)

Fot. 8. Widok na bramę nr 3 w Ogrodzie Botanicznym w Szanghaju (zbiory autora)

Through the use of living vegetation, economic and natural functions are performed in commercial areas. Plants reduce the ambient temperature, purify both harmful air and water from the harmful substances. In the summer it is much cooler under the roof, which prevents excessive use of cooling devices, it acts antagonistically in the winter, heating the spaces. Of course, in the tropicarium or cactus garden, it does not matter, because throughout the year there is maintained constant and same temperature, and very high humidity ideal for the development of tropical and exotic plants and temperature designed to preserve the natural climate of cacti and succulents.

3.1.5. Shanghai Botanical Garden, Gate 3, 997 Longwu Rd, Xuhui Qu

Another example from the Shanghai Botanical Garden is Gate 3, in the western part of the garden (Photo 8). It is a large passage, where there are toilets for tourists, a small shop with drinks and snacks, and gates, ticket office and tourist information. The whole roof is covered with sod and shrubs. The roof is also in an irregular shape. At the top flat with a slight inclination, it has the shape of a trapezoid, because the roof slopes fall to the ground with a greater inclination, even up to 60%. The roof area is approximately 120 m^2. Gate with a green, live roof can be considered as an example of extensive planting, due to the large amount of turf. It is not known when the roof was built.

It fulfills natural, economic, but above all spatial and social functions. The use of planting: masks the uninteresting and raw form of the entrance gate, refers to the character and function of the place, in this case to the Botanical Garden, harmonizes with the surroundings, definitely increases the attractiveness of the gate, causes the concrete block does not stand out against trees and green landscape, but blends together, gives a modern character to the traditional garden assumptions.

3.1.6. Shanghai Botanical Garden, Main Gate, 997 Longwu Rd, Xuhui Qu,

Another gate to the Botanical Garden (Photo 9). This time, the main gate located in the southwestern part of the park. As in the previous example, the date when the roof was built is unknown. It is a huge building, consisting of several parts of the roof slopes. The form is geometrized, broken, with many inclinations. The area is estimated tobe approximately 2,000 m^2. It is a completely extensive roof with a varied slope in the range of 5 to 60%. Just like the previous green roofs located in the area of the botanical garden, you can climb to the top here. A wooden path is led down from the bottom, with a green belt next to it, with quite a large slope. It is part of the roof, it is connected to a flat roof slope. Wooden terraces were created at the top to facilitate movement. As mentioned before, the roof is divided, in the middle part a concrete staircase was built, connecting the roof with the entrance to the building from the side of the car park. The right part of the roof goes down a gentle slope with a slight inclination towards the parking lot. The whole body of the building from the garden side is covered with a turf, stacked in high, sharp cut hills, aimed at masking the concrete, industrial walls of the façade. This roof fulfills all functions, such as aesthetic, economic, natural or social functions. It increases the attractiveness of the place and harmonizes with the surroundings, but above all it perfectly fulfills the economic assumption. Thanks to the use of grass, the indoor air temperature is much lower in the summer compared to the outside temperature. In addition, the building wall does not heat up, and the heating and cooling equipment is less exploited.

Photo 9. Green roof on a Main Gate in Botanical Garden, Shanghai (Author's collection)

Fot. 9. Zielony dach na głównej bramie w Ogrodzie Botanicznym w Szanghaju (zbiory autora)

3.1.7. Offices for design company

It is a complex of twelve buildings (Photo 10), for the time being unused. The total area of all roofs is about 9000 m^2. These are undeveloped buildings, currently vacant. The oral information, heard from the residents of the city, shows that the buildings will be developed as the headquarters of the design office. However, no information was obtained whether only a part of them was to be adapted for the office or all of them. However, it is known that these are new buildings, created at the turn of 2016/2017. They are located near Renmin Street, leading to the University campus. In the immediate vicinity of the river and walking paths. The roofs are entirely lined with an artificial grass roll (Photo 11). Roofs do not meet natural and eco-

Photo 10. View on an artificial green roofs, Changsha (Author's collection)

Fot. 10. Widok na sztuczne zielone dachy, Changsha (zbiory autora)

Photo 11. Detail on an artificial green roof, Changsha (Author's collection)

Fot. 11. Detal na sztucznym zielonym dachu, Changsha (zbiory autora)

Photo 12. Green roof on a Library, Changsha (Author's collection)

Fot. 12. Zielony dach na bibliotece, Changsha (zbiory autora)

Photo 13. Green roof on a Library, Changsha (Author's collection)

Fot. 13. Zielony dach na bibliotece, Changsha (zbiory autora)

nomic aspects. They are a perfect example for the solution of aesthetic and social functions. Roofs with their shape, form and cover attract attention, give the place an individual and unique character.

3.1.8. Green roof on a library building Hunan Agricultural University in Changsha

Hunan Agricultural University (HUNAU), is a key provincial university of Hunan with a huge campus with terrain of 2.27 km^2, campus is situated in Furong District of Changsha. HUNAU was established in 1951 on the basis of two colleges: the Agricultural College of Hunan University and the Hunan Provincial Xiuye Agricultural and Forestry College, and it was called Hunan Agricultural College. Later it was renamed as Hunan Agricultural University in 1994. The library is located in the central part of the Campus of Hunan Agricultural University in Changsha. From the north, surrounded by dormitories and residential buildings, from the south by university buildings.

The green roof project at the university library was implemented at the turn of 2016 and 2017 (Photo 12). Work on the construction began in autumn 2016. The roof was classified as extensive and semi-intensive. The slope varies from 2 to 5%, it is flat, open to students. A place has been created where students can rest and meet during breaks. The roof has been divided into 2 zones: living and utility. Many species of perennials, shrubs and small trees have been planted there (Photo 12).

The roof fulfills all functions: aesthetic, natural, economic and social. In addition, it integrates students and makes each of them involved in the process of creating and developing a garden on the roof, by planting and using a vegetable discount.

The assumption of the project was to create a student-friendly environment. The development of an open roof on the sixth floor of the university library. The elements characterizing this space were to be a reading corner, a place to relax, a small vegetable garden, as a "Horticulture Community garden", which students could use. The vegetable plant was planted, among others, tomatoes, hot peppers, herbs, complemented by small fruit trees.

To enrich the project, many materials were used, such as stone, steel, plastic steel, wood, and various shapes of seats (Photo 13).

A multi-level garden was made, through the use of wooden terraces, to which steps lead, different heights. Around the stone pillars supporting the roof constructions, wooden pots were planted, in which the creepers were planted, in this case a shade-loving ivy, above it a wooden trellage was set up, after which the plant would run. Also, extensive planting was arranged above the roof entrance. All pipes, pipes and ventilation chimneys were concealed or covered with plants, wooden trestles and landings, if possible. In order to supply water to plants, a combined irrigation system with rotary sprinklers was used.

4. Conclusions

Creating green roofs in cities is a relatively new trend, entering the trade market as an alternative form of greenery. It is a way to expand the biologically active area in highly urbanized cities. In addition, it meets many other aspects that only speak in favor of green roofs. They clean the air from pollution, collect rainwater, reduce the risk of flooding, normalize the temperature in cities and limit the effect of the so-called Urban Heat Island, reduce the heating and cooling costs of the building on which they exist, create new habitats for small animals. Creating gardens on roofs has only positive aspects. In addition, they are a feeding place for birds, small rodents, a habitat for insects or butterflies. In the social aspect, particular attention should be paid to the fact that the creation of such green forms favors and strongly affects people's well-being. An example of an open roof, which is, inter alia, a semi-intensive green roof on the Changsha library building, creates a new place of social integration, and the possibility of using public places.

There are several facilities in three cities in China. They were subjected to a detailed analysis, while the comparison of selected roofs took into account some of the most important features, characteristic for given examples, such as occupied surface, slope, roof type, type of green roof or planting types. Particular attention has been paid to the information elements, because they are comparative sources, giving the image of existing extensive roofs in the city, the benefits of setting up green roofs, differences resulting from the multitude of ways to create such surfaces and foreign ideas, in this case Chinese, architects and creators .

Roofs that have been analyzed, in some cases show no economic and ecological potential, but all meet the aesthetic and social conditions. In China, the aesthetics and attractiveness of the place (as in the case of artificial roofs) and the function of integrating the community are the greatest value. For comparison, in Western Europe, in cities such as Berlin, Frankfurt, Amsterdam, London and Copenhagen there are programs regarding Green Roofs. Since 2009, some cities has launched a green roof incentive program to grant direct subsidies for building owners to install a green roof. The program offers to cover 50% of the installation costs (Versini et al. 2020). Since 2010, the implementation of green roofs is required on all new buildings with roof slopes of less than 30 degrees. The main premise of such a policy pursued by cities is the extension of the biologically active area, action against climate change climate change, air purification, action against UHI. Therefore, the main feature that must be met are ecological and economic aspects, less important in this case is the aesthetic and social function.

References

Baik J.-J., Kwak K.-H., Park S.-B, Ryu Y.-H, 2012. Effects of building roof greening on air quality in street canyons. Atmos. Environ., 61.

Chen Y., 2002. An investigation of the effect of shading with vertical landscaping in Singapure. Use of Vegetation in Civil Engineering, London.

Cook-Patton S.C., Bauerle T.L., 2012. Potential benefits of plant diversity on vegetated roofs: a literature review. J. Environ. Manage., 106.

Davidson A., 1998. Summer in the city: NASA turns technology toward the Earth to determine what, exactly, makes cities so hot. Atrodams: http://www. metropolismag. com/new/content/tech/aug98sum. htm. [3.06.2019].

Francis L.F.M., Jensen M.B., 2017. Benefits of green roofs: a systematic review of the evidence for three ecosystem services. Urban For. Urban Green., 28.

Harazono Y., 1990/1991. Effects of rooftop vegetation using artificial substrates on the urban climate and the thermal load of buildings. Energy and Buildings, 15–16.

Hopkins G., Goodwin Ch., 2011. Living architecture. Green roof and walls. International Green Roof Association, 2006, Global Networking for Green Roofs, Green Roof News,

http://www.enghunan.gov.cn/Services/Live/Community/LMEH/201602/t20160203_2916066.html [10.08.2019].

http://www.snhm.org.cn:7070/gywm_eg/lssy.htm [11.08. 2019].

Kania A., Mioduszewska M., Płonka P., Rabiński J.A., Skarżyński D., Walter E., Weber-Siwirska M., 2013. Principles of designing and making green roofs and living walls. Guide for municipalities, Association of Municipalities of the Polish Network "Energie Cites", Cracow.

Kumar R., Kaushik S., 2005. Performance evaluation of green roof and shading for thermal protection of buildings. Energy and Buildings 40, 1505–1511.

Madre F., Vergnes A., Machon N., Clergeau P., 2014. Green roofs as habitats for wild plant species in urban landscapes: first insights from a large-scale sampling. Landsc. Urban Plan., 122.

Oberndorfer E., Lundholm J., Bass B., Coffman R.R, Doshi H., Dunnett N., Gaffin S., Köhler M., Liu K.K.Y., Rowe B., 2007. Green roofs as urban ecosystems: ecological structures, functions, and services. BioScience, 57.

Speak A.F., Rothwell J.J., Lindley S.J., Smith C.L., 2012. Urban particulate pollution reduction by four species of green roof vegetation in a UK city. Atmos. Environ., 61.

Velazquez L.S., 2005. Organic Greenroof Architecture: Sustainable Design for the New Millennium. Environmental Quality Management, Wiley Periodicals, Inc.

Versini P.-A., Gires A., Tchinguirinskaia I., Schertzer D., 2016. Toward an operational tool to simulate green roof hydrological impact at the basin scale: a new version of the distributed rainfall-runoff model Multi-Hydro. Water Sci. Technol., 74.

Versini P.-A., Gires A., Tchinguirinskaia I., Schertzer D., 2020. Fractal analysis of green roof spatial implementation in European cities. Urban Forestry & Urban Greening, 49.

Voelz J., 2006. The Characteristics & Benefits of Green Roofs In Urban Environments, Sustainability And The Built Environment. Uc Davis Extension.

Wong N.H., Chen Y., 2009. Tropical Urban heat islands. Climate, building and greenery. New York.

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Space, time and architecture – a new concept of garden development on the roof of the Vivo! shopping mall in Lublin

Przestrzeń, czas i architektura – nowa koncepcja zagospodarowania ogrodu na dachu galerii handlowej Vivo! w Lublinie

Abstract

Currently, we often observe how free spaces in the city center are occupied by more skyscrapers as well as retail and service facilities. Architects face increasingly difficult tasks of placing as many objects as possible in a strictly limited space. Decisions about the liquidation of greenery for another building often result from the lack of knowledge on the importance of vegetation in urban conditions. Green roofs can be a partial compensation for biologically active areas occupied by buildings. Gardens on the roofs, in addition to the aesthetic functions, favor the microclimate of the city. They absorb noise and air pollution, including heavy metals and dust. They lower the temperature, giving shade and providing shelter for birds and insects. With the use of modern technologies, we can create a foundation that does not extend far from the classical garden. We can use large trees, small architecture elements in the form of playgrounds or even a water reservoir in the spaces set up on the roofs of commercial buildings. This paper presents a new concept for garden development on the roof in the Vivo! Mall in Lublin. The mall was created in 2015 and is located at the junction of Aleja Tysiąclecia and Unii Lubelskiej, near the Old Town, the Castle and the bus station. Location of the object in the center of a downtown gives the place a chance to become a showcase of the city. The new vision of garden development presented in the paper is based on a plan of squares repeating in retaining walls, arbors, terraces and passageways. The project also presents proprietary projects of small architecture and sculptures as well as the selection of vegetation that will be attractive at any time of the year.

Streszczenie

Obecnie często obserwujemy, jak wolne przestrzenie w centrum miasta zajmują kolejne wieżowce i obiekty handlowo-usługowe. Architekci stają przed coraz trudniejszymi zadaniami umieszczenia jak największej liczby obiektów na ściśle ograniczonej przestrzeni. Zielone dachy mogą stanowić częściową rekompensatę terenów biologicznie czynnych zajętych przez zabudowę. W niniejszej pracy przedstawiono nową koncepcję zagospodarowania ogrodu na dachu w galerii handlowej Vivo! w Lublinie. Galeria powstała w 2015 r. i jest zlokalizowana u zbiegu al. Tysiąclecia i Unii Lubelskiej, w pobliżu Starego Miasta, Zamku i dworca PKS. Usytuowanie obiektu w centrum śródmieścia daje miejscu szansę na zostanie wizytówką miasta. Zaprezentowana w artykule nowa wizja zagospodarowania ogrodu opiera się na planie kwadratów powtarzających się w murkach oporowych, altanach, tarasach i ciągach komunikacyjnych. W projekcie przedstawiono również autorskie projekty obiektów małej architektury i rzeźb oraz dobór roślinności, który będzie atrakcyjny o każdej porze roku.

Key words: green roofs, Vivo! Mall, Lublin
Słowa kluczowe: zielone dachy, galeria handlowa Vivo!, Lublin

1. Introduction

Gardens on the roofs are visual, practical and ecological elements of the city's green infrastructure. The space, in which a person is staying, affects his behavior and well-being. In addition to aesthetic values, vegetation is an important factor in improving the quality of the environment. Plants purify the air by absorbing carbon dioxide and producing the oxygen in the process of photosynthesis. Due to the ability of phytoremediation or absorbing harmful substances from the environment by accumulating them in leaves or shoots, greenery is a barrier that isolates residential buildings from dust and exhaust gas from streets. Many plants extract bacteria and fungi by isolating the phytoncides. Greenery negatively ionizes and moisturizes the air, which positively affects the process of breathing and blood circulation. It lowers stress and positively affects the nervous system (Haber and Urbański 2005; Stovin et al. 2014; Drozd 2015; Ociepa-Kubicka 2015; Pęczkowski et al. 2016; Coma et al. 2017).

Currently, we often observe how free spaces in the city center are occupied by more skyscrapers as well as retail and service facilities. Architects face increasingly difficult tasks of placing as many objects as possible in a strictly limited space. Decisions about the liquidation of greenery for another building often result from a lack of knowledge on the importance of vegetation in urban conditions. Green roofs can be a partial compensation for biologically active areas occupied by buildings. About 2500 years ago, lead and asphalt became the basic building blocks for creating an amazing structure in the desert – the Semiramids Gardens. Today, similar objects are put together with the help of much more advanced technology and certified materials. In antiquity, technology allowed for the creation of relatively large roof gardens with abundant vegetation and elements such as swimming pools or small ponds. In the 21st century, a garden on the top of a skyscraper, library or mall is not unusual. In a sense, this is a forced solution due to the lack of space for the "classic" garden accompanying the object. This is an interesting solution, and in addition, it raises the rank of such a place. Green roofs on public utilities also contribute to the spread of this trend also to other construction objects (Kadas 2003; Peck et al. 2010; Szajda-Birnfeld et al. 2012; Wolański 2018).

Lublin is the largest city on the eastern side of the Vistula River, the capital of the Lublin province. Lublin is located on loess and chalk hills, between the valleys of three rivers (Bystrzyca, Czerniejówka, Czechówka) and Zalew Zemborzycki, which determines the landscape values of the city. The landscape of Śródmieście is strongly urbanized, where the human impact prevails; it is dated at least since the 11th century. It is dominated by dense urban buildings of quarterly character with numerous characteristic dominants of church towers and other monuments. The area is densely built-up; there are few areas covered with vegetation.

Permanent changes – fashion trends, the pursuit of new solutions in architecture, affect the space around us. The desire to introduce progressive, pioneer solutions determines the projects of subsequent architects. Each new architectural concept should refer to the respect of the history of a place, its destination, and facilities existing in its vicinity. It often happens that the space is associated with specific historical events or people – rulers, poets, artists, etc., who had an impact on its current image. The area, where the Vivo! shopping mall is located, was occupied by the Wielki Staw Królewski from the 14th to the 19th century. In the immediate vicinity of the mall, there is a 12th-century castle, the Old Town Square and a part of the former Jewish quarter, including Kierkut. Currently, many contemporary designs with their size or futuristic shape dominate over the surrounding landscape. Sometimes, they even disfigure the neighborhood of beautiful, historic buildings or disturb the panorama. This mall is a great example of how, using a simple form, subtle colors and natural materials, despite the size of the entire foundation, it can be "hidden" in the city space.

The Vivo! Mall is located in close proximity to the castle hill. In historical terms, these areas were marshy foregrounds of the castle, historical sources mention the extensive Royal Park that was located here. Specific geological and hydrological conditions, protection of the city panorama and valuable ecological structure determined the difficulty of the entire investment. Thus, one of the conditions for its construction became a record of the need to make green roofs, the character of which should resemble the surrounding landscapes, in particular, the riverside landscape of the neighboring watercourse. This indication proved to be quite difficult to implement due to the fact that gardens on the roofs are rather low in water and it is not possible to introduce vegetation growing on wetlands. Ultimately, the specifics of the species selection consisted in the fact that it was based on native forms occurring throughout Lublin and its vicinity. The source of inspiration was both species occurring on xerothermic grasslands found in the Czechowskie Hills, as well as vegetation of the Czechówka River Valley. However, in the following years of the garden functioning, the tenants of commercial premises as well as residents of Lublin reported on the aesthetics of the assumption (Trzaskowska and Szkołut 2016).

The appearance of another mall is always very popular. In addition to a strictly commercial function, there are a number of places for recreation gyms, a cinema, and gastronomy. Many leading fashion dictators (Chanel, Dior, Versace) commissioned the interior design of their stores to world-renowned architects and designers. New collections are often presented in a non-conventional and bold manner. Artistic binding attracts enthusiasts of fashion brands as well as ordinary passers interested in modern and avant-garde design of shop windows. Interesting shape of the building and interior design have a positive impact on the growth of popularity of a given company/brand and its image, and help in acquiring new potential customers, who can leave their money there.

The purpose of the work is to present a new vision of the development of the Vivo! Mall gardens. Currently, the insufficient number of small architecture objects and places for active and passive rest for the users of the facility means that the potential of the place does not seem fully utilized. The conceptual design provides for the creation of zones corresponding to specific functions opened to the needs of users. It was also proposed to enrich the selection of species with new attractive varieties of trees, shrubs and herbaceous plants.

2. Material and methods

Chamber experiments (literature review), field studies and design work were carried out in 2017–2018. The field work consisted in performing a detailed dendrological inventory. Then, a number of analyses were carried out (communication, nature, composition, history and analysis of hydrological conditions). A questionnaire, in which 60 participants of various ages participated, was also conducted. The questions concerned the appearance and functionality of the current assumption. Respondents also suggested direction of changes indicating strong and weak points of the mall roof. The above activities were an introduction to the implementation of the land development plan with new plantings, modernization of the communication system and small architecture facilities.

3. Green roofs – definition and meaning in the city

Definition of green roofs refers to objects, the roof of which is completely or partially covered by vegetation. When implementing a green roof project, it is necessary to cooperate with specialists from many fields: architects, constructors and gardeners, so that the building meets all safety standards. Structure of the ceiling and its maximum permissible load are equally important. In addition, the snow load in winter, rainwater and the weight of people staying in its area should be taken into account. If the design allows it in the project, then larger bushes or small trees can be included (Kania et al. 2013). Due to the plants used, green roofs can be divided into two main types (Szajda-Birnfeld et al. 2012). The concept of intensive roofs refers to places intended for the rest and recreation. Due to the increased thickness of the substrate, it is possible to use large bushes and trees. Due to large loads ranging from 290 kg/m^2 up to 1 500 kg/m^2, the entire building must be appropriately prepared for this purpose. Discrepancies result from selected plant species and design solutions, along with small architecture in the form of sculptures, fountains or water reservoirs. Depending on the species used, thickness of the substrate layer reaches up to 100 cm. The standard roof with intensive vegetation is about 30 cm thick, which allows planting shrubs up to 200 cm in height, which translates into a load of 350–400 kg/m^2. Intense greenery is carried out on terraces in residential buildings or in underground parking lots.

Extensive assumptions are usually not generally available and they only fulfill aesthetic functions without the possibility of their use. They are usually founded on large areas of commercial and service facilities. Vegetation with high regenerative capacity able to survive spontaneously in difficult conditions, including xeromorphic steppe vegetation that is able to survive with a limited amount of water and substrate is used for planting. The cost associated with the construction of extensive roofs is much lower. Constructions do not require such complicated technical solutions and strong ceilings. They can often be installed on existing buildings after adequate ceiling insulation. Weight of a single-layer roofing structure usually does not exceed 50 kg/m^2, and in other cases, it varies between 70 and 170 kg/m^2, which is undoubtedly much smaller load than in the case of intensive roofs (Szajda-Birnfeld et al. 2012). Extensive greenery on roofs usually has no utility meaning. Its main task is to reproduce biologically active areas. This aspect is an important element of ecological and social policy of large agglomerations in North America and Asia. It has also a significant place in planning the space of urban centers in Germany, Switzerland and Austria, which are undoubtedly leaders in the application of this technology in Europe (Kożuchowski and Piątek-Kożuchowska 2008).

The use of green roofs in public spaces plays the role of a magnet attracting users, creating an integration space, in which the process of the society education in the field of ecology and sustainable development, simultaneously takes place. Gardens on roofs successfully complement the green urban infrastructure. A cohesive greenery system in cities is very important from the point of view of ecosystem functioning. Although they are artificially created by humans, they can be considered as patches and corridors necessary to achieve a landscape continuity in heavily urbanized areas. The installation of green roofs can be a way to offset the unfavorable visual conditions, and to mask fragments or entire buildings for better correspondence with the surrounding landscape (Valazquez 2005, Rabiński et al. 2013; Trzaskowska and Szkołut 2016). It is worth to refer to the impact on the microclimate at this local temperature. In urban conditions, exposed roof surfaces and façades can easily heat up and then give back the heat to the atmosphere. The surface temperature of traditional roofs can reach 80–100°C on a cloudless day. The resulting "urban heat island" contributes to the increase of temperature inside the agglomeration. In the case of gardens on roofs, the temperature of the roof surface is lower and amounts to 25–40°C (Rabiński et al. 2013). Green roofs significantly improve the water retention in the city. Depending on the type of roof installation during a single rain, water retention varies from 15 to 90%. Roofs covered with vegetation relieve the sewage even up to 80% compared to a roof made of traditional materials. During atmospheric precipitation, water that penetrates the soil substrate and then the filtration layers is purified, which is additional advantage. It is becoming increasingly popular to capture rainwater blown through the green roof, and then its storage and use. The obvious role of green roofs is also participation in increasing the biodiversity. Small animals that would never live on a roof without a green dome, appear there. Butterflies are particularly easy to notice (Minke 2000; Brenneisen 2003), which were, what is worth emphasizing, always observed during the field studies conducted at Vivo! Mall (Trzaskowska and Szkołut 2016).

Although the construction of a green roof is associated with higher cost than covering with traditional materials, but in retrospect, it is a good investment. Green roofs have a great effect on the building's thermal energy, reduce the costs of air conditioning during warm days and influence the inhibition of heat loss, which minimizes the cost of heating. Limiting the energy needed to heat and cool the building can significantly reduce the cost of maintaining the facility, prevents the installation of additional heating and air conditioning devices. It is estimated that a green roof with a thickness of 20 cm and 40 cm of vegetation, prevents from the loss of heat the same way as 20 cm of traditional warming with mineral wool.

Green roofs emphasize the importance of the building and, as a result, its value by up to 15%. Office buildings with such an assumption can use them in various ways, e.g. by placing a bar or a café among greenery, it can be a place of painting exhibitions, a center of poetic meetings or just a place of rest for employees.

4. Research facility

The development area is located on the roof of the mall in the city center of Lublin. The building is located at the intersection of Aleja Tysiąclecia and Unii Lubelskiej streets near the roundabout Roman Dmowski. In the vicinity of the building, there is the Lublin Castle, PKS Bus Station and allotment gardens. In March 2015, the building was put into use to gain commercial and service functions. In 2019, the object changed its name from Tarasy Zamkowe to Vivo! The total area of the building is 104,000 m^2 and the retail and service area is 38 000 m^2. The type of building is qualified as a low-rise building with one above-ground storey, a heavily developed underground level containing a retail and service part, a parking lot, and an observation deck with a garden foundation (Photo 1 and 2). The roof has a beautiful view of the castle hill and the Old Town. Currently, the space consists of 2 parts: a flower meadow on a technical roof, to which there is no access – a space in the shape of permeating triangles (about 9 700 m^2) and an intense roof (about 5 800 m^2), which is accessible for public and has an infrastructure for visitors (information plates on plants, paths, benches, water bottle). The current roof plan is shown in Figure 1. It can be entered from the level of the pavement, from the terrace outside the gallery and from the inside (entry by lift marked "entrance to the terrace"). The roof of Vivo! Mall is available 7 days a week. The basic design assumption of the Stelmach and Partnerzy studio was to create a vast, green space referring

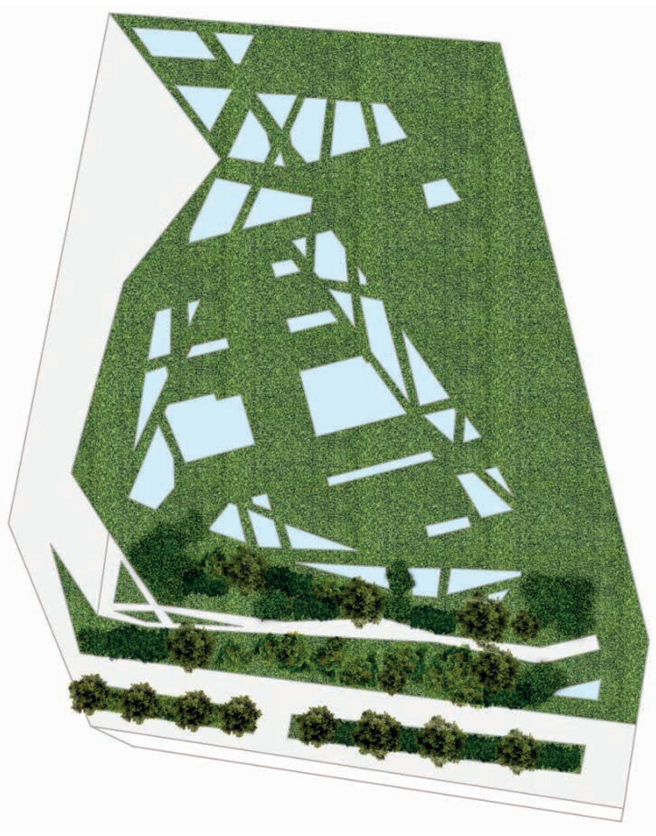

Fig. 1. Roof garden of the Shopping gallery Vivo! – current state (by P. Krupiński)

Ryc. 1. Ogród na dachu galerii handlowej Vivo! – stan obecny (opracowanie P. Krupiński)

Photo 1. Extensive roof at Galeria Vivo! in Lublin, 2018 (photo M. Dudkiewicz)

Fot. 1. Dach ekstensywny na galerii Vivo! w Lublinie, 2018 r. (fot. M. Dudkiewicz)

Photo 2. Intensive roof at Mall Vivo! in Lublin, 2018 (photo M. Dudkiewicz)

Fot. 2. Dach intensywny na galerii Vivo! w Lublinie, 2018 r. (fot. M. Dudkiewicz)

to the natural riverside landscapes of the Bystrzyca river valley on the roof of Vivo! Mall. The attempt to build a river valley ecosystem on the green roof is rather original idea. Typically, the selection of vegetation for this type of objects is limited to xerothermic vegetation.

5. Inventory results

The extensive part is made up of low plants that make up the flower meadow. Among many species, the following can be distinguished: *Allium sphaerocephalon*, *Briza media*, *Campanula carpatica*, *Dianthus arenarius*, *Festuca glauca*, *Festuca amethystica*, *Koeleria glauca*, *Phlox subulata*, *Salvia pratensis*, *Sedum*, *Sempervivum*, *Thymus serpyllum* and other. The extensively part of the roof gradually descends towards the north (Photo 1).

The other part of the roof is intense greenery (Photo 2). Here, the thickness of the soil substrate is greater than in the rest of the terrace. The narrow strips of intense greenery also accompany the stairs leading to the roof of the building. This part of the garden is located in the south-western part of the building. Twenty-eight tree and 19 shrub species were inventoried (Table 1 and 2). There are also grown here: *Festuca gautieri, Festuca glaca, Hyssopus officinalis, Iris pseudacorus, Iris sibirica, Miscanthus sinensis* 'Gracillimus', *Molinia caerulea* 'Variegata', *Lavandula angustifolia* and *Humulus lupulus, Parthenocissus tricuspidata.*

Condition of vegetation on the roof of the Vivo! Mall was rated as very good. The greenery located there is a subject to continuous observation and care treatments. The assumption is relatively new, therefore during inventory studies, no negative parameters were found for the trees, shrubs, perennials and ornamental grasses growing there, thus the inventory table omits a detailed assessment of the condition of the plant material currently in the study area.

Strings of pedestrian communication lead from the stairs located on the west side of the

Table 1. List of trees in the gardens on the roof of the Vivo! Mall in Lublin, 2018 (Source: own study)

Tabela 1. Wykaz drzew na terenie ogrodów na dachu galerii Vivo! w Lublinie, 2018 r. (Źródło: opracowanie własne)

No.	Name	Number of trees	Dimensions of the smallest and largest specimen	
			Trunk circumference at a height of 1.3 m [cm]	Height [m]
1.	*Acer campestre* 'Elsrijk'	15	33–61	6–9
2.	*Acer platanoides* 'Summershade'	8	44–71	7–11
3.	*Betula utilis* 'Doorenbos'	5	54–73	8,5–11
Razem/Summary:		28		

Table 2. List of shrubs in the gardens on the roof of the Vivo! Mall in Lublin, 2018 (Source: own study)

Tabela 2. Wykaz krzewów na terenie ogrodów na dachu galerii Vivo! w Lublinie, 2018 r. (Źródło: opracowanie własne)

No.	Name	Dimensions of the smallest and largest specimen	
		Area [m²]	Wysokość [m]
1.	*Acer negundo* 'Odessanum'	3–11	2,5–5
2.	*Acer palmatum* 'Wilson's Pink Dwarf'	1	1
3.	*Berberis thunbergii*	2	1,5
4.	*Berberis thunbergii* 'Atropurpurea Nana'	2–108	1–1,5
5.	*Berberis thunbergii* 'Atropurpurea'	2	1,5
6.	*Berberys thunbergii* 'Diabolicum'	12	0,8
7.	*Berberys thunbergii* 'Green Carpet'	3	1
8.	*Cotoneaster dammeri* 'Major'	7–125	0,1–0,2
9.	*Cotoneaster salicifolius*	7,5–70	0,2
10.	*Cotoneaster salicifolius* 'Parkteppich'	9–36	0,2–0,9
11.	*Rosa rugosa*	60	1,5
12.	*Ribes spicatum*	1–2	0,8–1,3
13.	*Salix caprea*	3,5–4,5	2
14.	*Salix repens* 'Nitida'	5,5–215	0,2–2
16.	*Viburnum opulus* 'Compactum'	1–30	0,6–1,3
17.	*Sambucus nigra* 'Aurea'	1–2	1–2,25
18.	*Spiraea japonica*	1	0,4
19.	*Ligustrum vulgare*	24	1

building to the south stairs and on the highest viewing terrace that runs along the southern edge of the building.

Lower parts of the observation deck and the stairs are made of concrete slabs, while on the highest part of the building, a visitor can navigate through gravel passageways.

6. A new development concept

The inspiration for the new founding concept was the authors' interest in modernist architecture, both in buildings and gardens (Figures 2–4). Introduction of bright gravel communication routes contrasting with the surrounding greenery will give a feeling of peace and order. A simple form, avoiding decorations, minimalism in a sense, are features that perfectly fit into the assumptions on the roofs (Newbury 2005). The building itself and its immediate surroundings also have their share in the final composition of the designed garden. In part with an extensive vegetation, the project involves the creation of small embankments from the north and east. This is related to a slight increase in the thickness of the soil substrate, which will not increase the load rapidly, and will allow to plant new vegetation in the form of low trees. This treatment is intended to cover unsightly views and make the extensive part attractive, which will become a combination of both types of plant cover on the roof. However, the part with intense vegetation would undergo major changes and rebuilding. The project assumes the construction of all roof layers as a landscape roof in the Optigrün system (Fig. 4), gravel passageways with an observation deck, retaining walls and a decorative garden. A new small architecture was planned in the form of benches, gazebos, lighting and elevated terraces. The vegetation is to give the assumption a new individual character and fit the form of the building and its surroundings. The project uses many species of trees with decorative leaves or bark, among others: *Betula pendula* 'Youngi', *Malus purpurea, Salix babylonica, Crataegus laevigata* 'Crimson Cloud'. The remaining spe-

Fig. 2. Roof development project for the Vivo! gallery roof (by M. Bartkowiak)

Ryc. 2. Projekt zagospodarowania dachu galerii Vivo! (oprac. M. Bartkowiak)

Fig. 3. Roof development project for the Vivo gallery roof! (by M. Bartkowiak)

Ryc. 3. Projekt zagospodarowania dachu galerii Vivo! (oprac. M. Bartkowiak)

Fig. 4. Roof development project for the Vivo gallery roof! – night visualization (by M. Bartkowiak)

Ryc.4. Projekt zagospodarowania dachu galerii Vivo! – wizualizacja nocna (oprac. M. Bartkowiak)

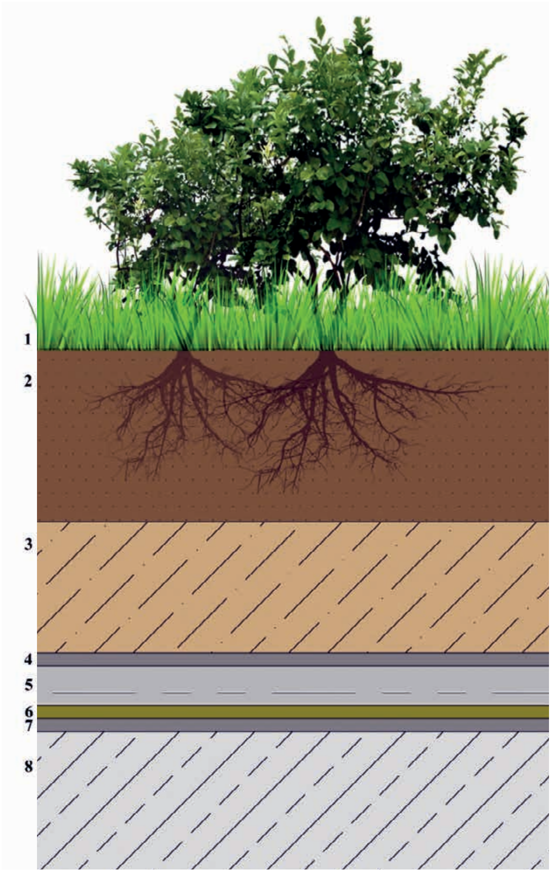

Fig. 5. The cross section through the designed roof. Layer: 1 – vegetation; 2 – intensive substrate; 3 – substrate; 4 – filter geotextile; 5 – bulk material; 6 – protective geotextile; 7 – waterproofing membrane; 8 – roof construction (by P. Krupiński)

Ryc. 5. Przekrój poprzeczny przez zaprojektowany dach. Warstwa: 1 – roślinność; 2 – intensywne podłoże; 3 – substrat; 4 – geowłóknina filtrująca; 5 – materiał sypki; 6 – geowłóknina ochronna; 7 – membrana hydroizolacyjna; 8 – konstrukcja dachu (oprac. P. Krupiński)

Table 3. Comparison between the old and the new solution (Source: own study)

Tabela 3. Porównanie starego i nowego rozwiązania (Źródło: opracowanie własne)

	Current state	Designed
Area	Extensive roof: approx. 9 700 m^2 Intensive roof: approx. 5 800 m^2	Surface unchanged. Changing the composition of the composition on the intensive roof
Construction	No system data	Landscape garden roof in the Optigreen system
Vegetation	28 specimens of trees, 19 species of shrubs with a total area of 2 850 m^2	17 trees of 9 species were planned; 380 shrubs from 20 species; and 4 600 items perennials and grasses
Function	Passive rest (walking, sitting), average number of ornamental plants	active and passive leisure (e.g. playground), lots of decorative plants, arbors, pergolas, small fountains

cies are shrubs with decorative leaves: *Salix integra* 'Hakuro-Nishiki', *Euonymus fortunei* 'Emerald`n Gold', *Berberis thunbergii* 'Aurea', *Chaenomeles speciosa, Callicarpa dichotoma* 'Issai', *Euonymus alatus* and *Berberys thunbergii* 'Orange Rocket'. The composition is complemented by perennials and ornamental grasses. The garden will be a fully accessible place, fulfilling a social function and an interesting attraction for the city. Comparison of the current state with the planned one is presented in Table 3.

7. Conclusions

The new concept of garden development on the roof of the Vivo! Mall in Lublin aims at creating a public space of a recreational and leisure nature taking into account the needs and expectations of the mall users and residents of the city. Among dense downtown buildings, the adaptation of mall roofs to urban gardens seems to be a good solution. Planned objects are visually also more interesting and more willingly visited by residents, as well as tourists from other cities.

The new vision of the roof garden is based on a square plan, the form of which is repeated in the shape of retaining walls, gazebos, terraces and passageways. The project also includes proprietary small architecture designs and a new selection of vegetation that adapts to the concept of the assumption and meets the conditions on roofs with intense vegetation. The authors of the new garden design at the Vivo! and at the same time the authors of this article hope that the presented concept will be used in further discussion on the greenery of Lublin and the greening of shopping center roofs.

References

Bańka A., 2002. Społeczna psychologia środowiskowa. WN Scholar, Warszawa.

Brenneisen S., 2003. Refugium fűr Flora und Fauna. Garten + Landschaft 10.

Coma J., Pérez G., Gracia A., Burés S., Urrestarazu M., Cabeza L., 2017. Vertical greenery systems for energy savings in buildings: A comparative study between green walls and green facades. Building and Environment, 111, 228–237.

Drozd W., 2015. Dachy zielone rozwiązaniem dla obiektów budowlanych. Przegląd Budowlany, 4, 14–21.

Haber Z., Urbański P., 2005. Kształtowanie terenów zieleni z elementami ekologii. Wyd. AR w Poznaniu, Poznań.

Kadas G., 2003. Study of Invertebrates on Green Roofs: How Roof Design Can Maximise Biodiversity in an Urban Environment. Master's Thesis. Royal Holloway, University College, London.

Kania A., Mioduszewska M., Płonka M., Rabiński J.A., Skarżyński D., Walter E., Weber-Siwirska M., 2013. Zasady projektowania i wykonywania zielonych dachów i żyjących ścian. Stowarzyszenie Gmin Polska Sieć „Energie Cites" Kraków.

Kożuchowski P., Piątek-Kożuchowska E., 2008. Dachy zielone w Polsce, próba podsumowania doświadczeń ostatniej dekady [in:] Problemy zagospodarowania wód opadowych (ed.) J. Łomotowski. Wyd. Sedel-Przywecki, Wrocław.

Minke G., 2000. Dächer begrűnen einfach und wirkungsvoll. Freiburg.

Newbury T., 2005. Sztuka projektowania ogrodów. Wyd. Elipsa, Warszawa.

Ociepa-Kubicka A., 2015. Ekonomiczne i ekologiczne aspekty zielonych dachów. Zeszyty Naukowe Wyższej Szkoły Bankowej we Wrocławiu, 2, 289–296.

Peck S., Callaghan C., Bass B., 2010. Greenbacks from green roofs: forging a new industry in Canada: Status Report on Benefits, Barriers and Opportunities for Green Roof and Vertical Garden Technology Diffusion. Canada Mortgage and Housing Corporation, Ottawa, ON.

Pęczkowski G., Orzepowski W., Pokładek R., Kowalczyk T., Żmuda R., Wójcik R., 2016. Właściwości retencyjne zielonych dachów typu ekstensywnego na przykładzie badań modelowych. Acta Sci. Pol. Formatio Circumiectus, 15 (3), 113–120.

Rabiński J., Skarżyński D., Walter E., Weber-Siwierska M., 2013. Krótka historia zielonych dachów [in:] Zasady projektowania i wykonywania zielonych dachów i żyjących ścian. Poradnik dla gmin. Stowarzyszenie Gmin Polska Sieć „Energie Cites", Kraków, 27–38.

Stowin V., Poe S., Berretta Ch., 2013. A modelling study of long term green roof retention performance. Journal of Environmental Management, 131, 206–215.

Szajda-Birnfeld E., Pływaczyk A., Skarżyński D., 2012. Zielone dachy. Zrównoważona gospodarka wodna na terenach zurbanizowanych. Wydawnictwo Uniwersytetu Przyrodniczego we Wrocławiu.

Trzaskowska E., Szkołut P., 2016. Zastosowanie roślinności naturalnej w doborze gatunków w ekstensywnym ogrodzie na dachu Tarasów Zamkowych w Lublinie [in:] Krajobrazy Lublina, (ed.) E. Trzakowska, P. Adamiec, 69–84.

Valazquez S., 2005. Organic Greenroof Architecture: Sustainable Design for the New Millennium. Environmental Quality Management Wiley Periodicals, 40.

Wolański P., 2018. Zastosowanie dachów zielonych w budynkach użyteczności publicznej i obiektach komercyjnych. Nowoczesne Hale, 2, 26–29.

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Possibilities of implementing green infrastructure in modern cities through its applications in workplace architecture

Możliwości wdrożenia zielonej infrastruktury we współczesnych miastach poprzez jej aplikacje w architekturze miejsc pracy

Abstract

Implementation of green infrastructure in modern cities should take place not only in public space, but also with the use of architectural objects. This is particularly important in the architecture of workplaces, which is an inherent spatial element of human life in a city. The benefits of such a measure affect not only the workers, but also the inhabitants of the cities and the urban landscape. However, the increasingly popular application of green roofs and vertical greenery requires constant research and analysis in order to implement it more widely in Poland. Improvement of the quality of the environment and working environment through the responsible use of plant elements becomes a fact and a need of today's developing city and people living and operating in the relevant professional field. The aim of the research is to illustrate the possibilities of implementing greenery in work-space by giving it utilitarian functions.

Streszczenie

Wdrażanie zielonej infrastruktury we współczesnych miastach powinno odbywać się nie tylko w przestrzeniach publicznych, ale również przy wykorzystaniu obiektów architektonicznych. Szczególnie ważne jest to w architekturze miejsc pracy, która stanowi nieodłączny element przestrzenny życia ludzkiego w mieście. Korzyści płynące z implementacji zieleni w architekturę miejsc pracy wpływają nie tylko na jej użytkowników, lecz także na mieszkańców danego miasta i krajobraz miejski. Coraz popularniejsze zastosowanie dachów zielonych oraz zieleni wertykalnej wymaga ciągłego badania i poddawania analizie w celu jej szerszej implementacji na warunki polskie. Podniesienie jakości otoczenia i środowiska pracy poprzez odpowiedzialne wykorzystanie elementów roślinnych staje się faktem i potrzebą współcześnie rozwijającego się miasta oraz ludzi w nim żyjących i funkcjonujących w danej dziedzinie zawodowej. Celem badań jest zobrazowanie możliwości implementacji zieleni w miejscu pracy poprzez nadanie jej funkcji użytkowej.

Key words: greenery, green walls, architecture of workplaces
Słowa kluczowe: zieleń, ściany zielone, architektura miejsc pracy

1. Introduction

Workplace architecture is identifiable in most types of buildings. It is present, among others, in service and commercial construction, public buildings, education, culture, health care and many others. Together, these buildings and the surrounding area form an urban structure. Consideration of investments in green areas in workplace architecture may undoubtedly have a significant impact on the greening of cities, improving working environment and workers' health (Zelinsky 2002). The research subject matter undertaken is also related to the issues of dialogue between architecture and ecology (McGrath 2017).

The application of greenery in any type of architecture is connected with the involvement of particular investment parties in projects concerning plant areas and installations. In order to positively consider the proposed design solutions involving greenery, it is important to present appropriate arguments to the parties making decisions about starting the investment. To this end, it is important to understand that architectural design is, among other things, a response to the need for people who use it to fulfil certain functions (Friedman 2014). Taking into account the type of architectural objects considered the architecture of workplaces, the answer to the question of what can be the function of greenery in employee objects should be found.

The aim of the research is to present ways of using greenery as an interactive function in the architecture of workplaces and to diagnose preferences of office workers of selected solutions.

2. Materials and methods

In order to identify the function of greenery in workplace architecture, the methodology of literature research, walk through (Niezabitowska 2014), environmental interviews, statistical and quantitative methods, and the CAWI method (DJ Research LTD. 2008) were used. For the purposes of the research process, foreign reference examples were collected to present the use of greenery in the workplace. Selected facilities are characterized by a strong position on the international economic market and use the latest available technologies. For comparison, three Polish architectural examples are also presented (Table 1). The functional and spatial arrangements of Polish objects were analysed in terms of locating and using greenery in the interiors of selected buildings and their surroundings. In order to verify the conducted analyses, a questionnaire survey was conducted in June 2019, in which 43 Polish employees participated (Table 2). The aim of the research was to determine the function of greenery in the architecture of workplaces and to detect its demand in Polish working conditions. The results of the research aim to outline the ways of implementing greenery in polish workplace architecture.

3. Analyses of types of green functions in workplace architecture

The research carried out on selected examples of foreign workplace architectures was based on the analysis of projection plans, descriptions of architects and users, and illustrative materials. 10 buildings were selected for the study, including Google's Dublin and Zurich office buildings. The objects that were also analysed were Timberland, Microsoft and Amazon.

3.1. Office Garden

One of the solutions for introducing greenery to the workplace is to implement an office garden for employees. These can be indoor, outdoor, roof or balcony gardens. In the research process, an interesting example of how an office garden can be given the function was identified at Timberland, located in New Hampshire, USA. The building has an outdoor office garden focused on growing plants, vegetables and fruits. Employees volunteer to participate in the breeding process during their working hours. The benefit is not only being outdoors during a long

Table 1. Architectural objects included in the research process (Source: own study)

Tabela 1. Obiekty architektoniczne zawarte w procesie badawczym (Źródło: opracowanie własne)

Foregin architecture objects, localization, date, architect	Polish architecture objects, localization, date, architect	Research methodology
1. Timberland Office, New Hampshire, lack of object data 2. Google Office, Dublin, 2011, Camenzind Evolution, Henry J. Lyons Architects 3. Google Office, Zurich, 2007, Camenzind Evolution 4. Google Office, Tel Aviv, 2012, Camenzind Evolution 5. Microsoft Treehouse, Redmond, 2017, Pete Nelson 6. Amazon Spheres, Seattle, 2018, NBBJ 7. Urban Forest, Munich, 2019 project, Herzog & de Meuron 8. Olswang LLP, London, lack of object data 9. KKCG AG, Praga, renovation 2013, VRTIŠKA ŽÁK 10. Reservoir, Rajasthan, project, Sanjay Puri Architects	1. SPARK Skanska Office, Warsaw, 2018, Workplace & Florabo (interior design) 2. Xsolve Office, Gliwice, 2016, Rafał Drobczyk 3. Future Processing, Gliwice, 2011, MFA Studio 4. G.EN. Gaz Energia, Tarnowo Podgórne, lack of object data	Statistical and quantitive methods based on literature resorces; Functional analysis of plans; Spatial arrangement analysis; Walk through method and interviews with workers were conducted at Xsolve, Future Processign and G.EN. Gaz Energia office; Analyses of greenery locations and function

Table 2. Data for CAWI method (Source: own study)

Tabela 2. Dane przyjęte do badań CAWI (Źródło: opracowanie własne)

CAWI method data	
Date	June 2019
Number of participants	43
Age of participants	type I – 18–20 years old type II – 21–30 years old type III – 31–40 years old type IV – more than 41 years old
Nationality	Polish
Type of workplace	office
Type of workspace	type I – cubical type II – open space type III – single room type IV – other type

working day, but also having a green space for integration between employees based on common cultivation activities. Thanks to the activities of the Timberland owners, this particular office garden also serves the local community. The fruit is destined for the local New Hampshire Food Bank (3BL Media 2017). According to the data collected, a total of $12,000 was donated by the company by 2017 as a result of this activity. The owners of the company are proud of this investment also because it encourages employees to create their own home gardens.

Office gardens are one of the most universal solutions accompanying the shaping of greenery in the workplace. They can be located outside, but also inside the building. The surface area of this type of solution can also be adapted to the size of the building. An interesting aspect is the possibility of selecting plants and at the same time the function of an office garden. It can be a breeding ground for flower, herbal, fruit or vegetable plants. Beekeeping can also be an integral part of office gardens, as it supports the process of pollinating flowers. Office gardens can also be used as a place for health therapy (Myszka Stąpór and Kosiacka Beck 2017). Getting involved in the processes of growing plants and staying outdoors stimulates the body and the senses. By positively influencing the mood, the presence in such a garden can reduce the negative effects of fatigue, stress and nervous tension during the working day.

3.2. The jungle in the office

An interesting use of greenery in the internal space of the architecture of workplaces is the creation of a room with plant themes. In this way, the designed room creates not only interesting visual effect, but can also support the processes of performing professional duties. In order to achieve the desired effect, it is necessary to maximize the use of horizontal and vertical areas for the location of plant elements. In this way, an internal environment is created that can affect not only one room individually but also the possibility of stimulating and maintaining appropriate air humidity and temperature in most parts of the building. The benefits of such a solution are certainly enjoyed by employees who can realize professional challenges in conditions inspired by nature. Google decided on such a solution, locating the jungle room in office buildings in Dublin and Zurich (Archdaily 2009). Such an investment has a positive impact on work by improving not only the aesthetics of the interior but also by creating better air quality for work and brain functioning. Google's Dublin office building has been recognised on an international platform and received numerous awards, including the A' Design Awards 2014 *Interior Space* – Platinum (A' Design Award & Competition 2014).

The Polish company Skanska (Property Design 2018) also decided on a similar solution. It completed its office in Warsaw using vertical and horizontal plant installation solutions. There are 536 plants per 100 m^2 of space. The project was carried out in accordance with the belief in a sustainable environment with which the company identifies itself. Investors wanted to create a place where you can feel like you are in nature. On the green wall, there are 396 plants on the ceiling. In addition, there are 20 pots with large and small plants in the space. The advantage of this particular office is the variety of applications of plant installation methods, both vertical on walls and ceilings and horizontal at floor level. The benefits of such a prepared space certainly have an impact not only on the comfort of work but also on its effects and the overall working environment.

3.3. Using the environment to support work processes

The use of the natural environment surrounding the facility for work-related activities seems to be an obvious solution. However, not all companies benefit from the natural values adjacent to the individual buildings. The company that decided to take advantage of the natural surroundings of the office building is Microsoft located in Redmond (Jewell 2017). The complex of company buildings surrounded by 500 acres of forest offers its employees very interesting working conditions. The company decided to build work-space in the form of popular treehouses. The author of the idea is Pete Nelson, who specializes in this type of investments (New York Post 2017). Cottages are designed for work, professional meetings and conferences. Working processes are fostered by direct contact with nature and the resulting unique atmosphere of peace and quiet. The aim of the company was to encourage employees to go outside in order to stimulate them to act, focus and be creative by means of greenery. According to the *Inhabitat* source (Jewell 2017), investors declare that this project was preceded by research, which showed that employees work more effectively in contact with nature.

3.4. Forest in the working city

The use of greenery in the workplace is connected with making a decision on the scale of the investment. Not all companies can and want to allocate high financial resources for this purpose. However, it is worth noting the directions in which corporate finance is invested in large companies, whose brand is known all over the world. The fact that large projects have been set up to introduce vegetation in the workplace certainly demonstrates the benefits of this measure not only for employees but also for employers. One such example is Amazon in Seattle (Cogley 2018). The company is located in buildings forming a complex of buildings. In 2018, a huge investment was made in their vicinity, focused in a special way on the use of vegetation in the office interior. The project called The Spheres is based on three interconnected space. These are the globes, which contain more than 400 species of plants. The highest of them is 17 m high (*Ficus rubiginosa*). The spheres are also open to Seattle residents at certain times so that the local community can experience the biodiversity in the city centre, as the investors claim. The building is supported by a complex system of temperature, humidity and daylight control. The largest of the spheres measures 27 m in height and 39 m in diameter. The facility is designed for about 800 employees. It is an excellent example of confronting the needs of employees in the context of difficult conditions of strict urban development. Inside the green spheres, employees may perform their professional duties in a completely different environment from what is offered by local conditions. Surrounded by greenery rich in biodiversity, employees can certainly boast a unique working environment (Schlosser 2018).

3.5. Multifunctional greenery

Maximum use of the function that can be performed by greenery in workplace facilities may be a favourable factor in the process of investment decisions related to the location of zones and plant objects in this type of construction. An interesting solution is the creation of a green zone in the courtyards of office buildings. It serves as both an external space supporting the creation of a sustainable urban environment and an internal zone for employees. Properly designed with pertinent surface parameters, it can also become a recreation area. This type of solution was proposed by Herzog & de Meuron (Walsh 2019, Urban Forest). The planned investment includes the revitalization of the existing building in order to adapt it to the needs of future users. The project is called *Urban Forest*. It was designed to create not only a sustainable working environment. It also purifies urban air and cools it, creating a friendly microclimate for residents and users.

3.6. Conclusions from the study on green functions in workplace architecture

The presented examples illustrate the role that greenery can play in the workplace. In the process of analysis and research, two leading groups of functional features for vegetation in workplace architecture were identified. The first one is a group of physical features, which result from the visual presence of greenery and actions initiated by them without interaction with man. Physical characteristics can be, for example, improved aesthetics and visual appearance, improved temperature control, improved microclimate, improved insulation or reduced energy costs. The second group of features are the functional characteristics of plants in the working environment. Their presence is evidenced by the possibility of interaction with the user of workplace architecture. This means that they create conditions for initiating physical or intellectual actions of the users of a given space. Their location and management, for example, encourages physical activity in the open air or generates integration between employees. The utility features of plants can be creating a platform for relaxation, creativity, physical activity, silence and focus zone, regeneration zone or self-improvement zone. The pursuit of both groups of characteristics, both physical and functional, can give vegetation a completely new function the functioning of a working tool (Fig. 1). Such use of green elements in the work environment will have a positive impact not only on the design in accordance with sustainable development strategies. Initiating integration between employees, influencing work comfort and creating a space that provides the necessary incentives to implement work processes may become a tool that influences the effectiveness of employees and their actions.

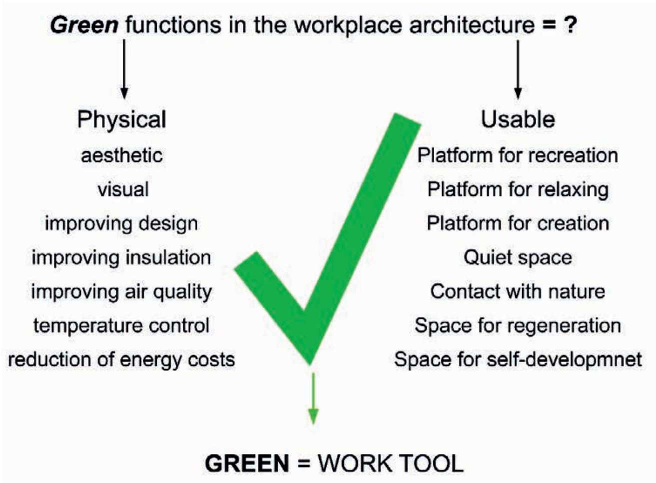

Fig. 1. Greenery functions in workplaces (Source: own study)

Ryc. 1. Funkcje zieleni w miejscach pracy (Źródło: opracowanie własne)

In this way to create a multifunctional roof, we can create space for recreation, sports or plant breeding. The satisfaction of needs related to contact with nature and silence and regeneration can be ensured by installing indoor green walls and plant pots. An important element in the process of designing greenery in employee facilities is to generate interaction between areas and green facilities and the users of a given building.

4. Results of research on the Polish working environment

In order to broaden the range of research results, the scope of the research was extended to include research connected to community interviews in selected Polish office buildings. The research covered the *Xsolve* and *Future Processing* office buildings located in Gliwice, as well as the *G. EN.* office building. *Gas Energy* is located in Tarnowo Podgórne. The results of the research illustrate two dominant types of greenery. These are pots with plants and the outer accompanying greenery. An interesting example was an office building in Tarnowo Podgórne, which has only internal potted greenery. The building is surrounded by a very attractive area rich in forests and fields. Despite the rich in natural values environment, the company does not provide employees with the possibility of using the accompanying area in any form. According to the community interviews, employees would like to use an outdoor garden. Their love for nature is noticeable in the interior, in which they perform their professional duties. The rooms are made more attractive by the employees with potted plants brought to work.

The results of the research were verified by extending their scale. For this purpose, a *CAWI* survey was conducted in June 2019. The aim of the research was to gain knowledge on the location of greenery in Polish objects of workplace architecture. The survey also studied the attitude of employees to the role of greenery, which they believe it plays in their place of employment. The survey involved 43 Polish office workers. It turns out that 65% of the respondents have greenery at their workplace. In the vast majority of cases it is in the form of pots, as much as 61%. Green walls are found in 7% of respondents. Green internal walls are also found only in 7% of respondents. Other forms of greenery located in the places of employment include plants located on balconies, office gardens and external green walls. An interesting result of the research turns out to be the attitude of Polish users of workplaces to greenery in their place of employment. As many as 96% of the surveyed people would like to have green space in their work-space or that there would be more green space than now. Moreover, over 83% of respondents believe that the presence of green areas in the workplace has a positive impact on the implementation of professional challenges.

4.1. Conclusions from greenery research in the Polish working environment

The results of research carried out in the Polish environment of workplace architecture clearly prove that greenery is desirable as an element accompanying this type of architecture. Persons participating in the study confirmed that plant elements positively influence their work. Research results directly reveals the desire to have greenery, which in the event of absence from the workplace is supplemented by employees with their own potted plants. Finally, as a result of the research process of Polish architecture, it was found that greenery is an important factor in shaping a proper and sustainable working environment. In order to give greenery the function of a working tool, it is important to design it in the way to give it proper physical and functional factors. The diversity of available solutions should be limited by the right choice of the role of greenery in the workplace. In order to achieve this goal, it is necessary to analyse the employee system, as well as participation with employees. At the end, they will be the final users and receivers of the green zones in the object.

5. Summary

As a result of the research, examples of greening of workplace architecture objects as an important component of urban structure are presented. Selected objects show the methodology and methods of localization of plant zones in this type of buildings. The availability of technological and material solutions available on the Polish market enables the implementation of plant zones in the investigated type of objects on a larger or smaller scale. In order to involve the members of the investment process in the implementation of areas and elements of greenery, it is necessary to argue this action by presenting the profits that can be obtained by locating vegetation in the workplace. By designing greenery in such a way that it becomes a working tool, we create opportunities for development not only for employees but also for the company in which they are employed. In order to achieve the goal of shaping green as a working tool, it is important to give it a usable and physical function. As a zone located in an object, it should serve as a zone with a specific function. The space in which it will be located should be designed in such a way as to initiate interactions with its users. This can be achieved by shaping, among other things, green recreational spaces, cultivated gardens or plant working spaces.

The research carried out shows what a chance for cities and their inhabitants' life can be the objects of architecture of workplaces where greenery and its elements are introduced. Such a procedure results in consistent action towards greening of settlement urban structures. As a result, it not only visually improves the working and living space, but also creates a friendly microclimate, maintains proper temperature and good air quality in highly urbanized cities.

The activities of the application of greenery in the architecture of workplaces are undoubtedly a step towards the aim of introducing vegetation into the structure of cities. Not only the technical aspects of the project are important, but also its functional aspects. Greenery should fulfil specific functions in the construction of workplace architecture. By initiating the interaction between vegetation and users of a given space, we give it the function of a working tool. It is becoming an invaluable factor in creating innovative and forward-looking working and living conditions in the city.

References

3BL Media, 2017. Timberlands Grows Vegetables, Funds, and Community. https://www.3blmedia.com/News/Timberland-Grows-Vegetables-Funds-and-Community [12.08.2019].

A' Design Awarad & Competition, 2014. Google Campus Dublin Office Interior Design by Camenzind, https://competition.adesignaward.com/design.php?ID=34381 [10.08.2019].

Archdaily, 2009. Google EMEA Engineering Hub / Camezind Evolution. https://www.archdaily.com/41400/google-emea-engineering-hub-camezind-evolution [10.12.2019].

Cogley B., 2018. Plant-filled spheres open at Amazon headquarters in Seattle https://www.dezeen.com/2018/01/30/plant-filled-seattle-spheres-open-amazon-headquarters/ [10.12.2019].

DJ Research Ltd., 2008. What is CAPI, CATI and CAWI? http://marketresearchworld.net/content/view/2114/78/ [10.08.2019].

Friedman R., 2014. The Best Place To Work, The Art and Science of Creating an Extraordinary Workplace. Penguin Group, New York.

Jewell N., 2017. Microsoft unveils amazing treehouses office where employees can brainstorm in fresh air. https://inhabitat.com/microsoft-unveils-amazing-treehouse-office-where-employees-can-brainstorm-in-fresh-air/ [10.12.2019].

McGrath B., 2017. Intersecting disciplinary frameworks: the architecture and ecology of the city. Taylor & Francis Group. https://www.tandfonline.com/doi/full/10.1080/18626033.2017.1425320

Myszka-Stąpór I., Kosiacka-Beck E., 2017. Hortitherapy as a method of treating civilizational diseases. Journal of Transport & Health, 5, S113-S114 New York Post.

Niezabitowska E.D., 2014. Metody i techniki badawcze w architekturze. Politechnika Śląska, Gliwice.

Property Design, 2018. Tu zieleń wylewa się na korytarze. Oto niezwykła przestrzeń Skanska szkicu Workplace i Florabo http://www.propertydesign.pl/design/185/tu_zielen_wylewa_sie_na_korytarze_oto_niezwykla_przestrzen_skanska_szkicu_workplace_i_florabo,19511–75363.html#img [10.08.2019].

Schlosser K., 2018. Welcome to Amazon's jungle: Inside The Spheres, where 40 000 plants create a stunning urban oasis. https://www.geekwire.com/2018/welcome-amazons-jungle-inside-spheres-40000-plants-create-office-like-no/ [10.08.2019].

Walsh N.P., 2019. Herzog & de Meuron Reveal „Urban Forest" Office in Munich. https://www.archdaily.com/921288/herzog-and-de-meuron-reveal-urban-forest-office-in-munich [10.08.2019].

Zelinsky M., 2002. Inspired Workplace, Design for Creativity & Productivity. Rocport Publisher Inc, China.

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The use of packaging waste in the concept of living wall in the public interior

Wykorzystanie odpadów opakowaniowych w koncepcji żywej ściany we wnętrzu publicznym

Abstract

The paper presents the idea of reusing packaging waste in the construction and designing of a living wall located inside a public building. The idea of using bottles (packaging waste) as construction material and a decorative element for making a living wall was presented. The construction and designing materials that are proposed in the design are mainly glass and plastic bottles. The structure of the living wall consists of a metal frame made of perforated profiles. The proposed plants are adapted to the conditions in the room in question. The installation includes an irrigation system for every level of the greenery. It was suggested that the green wall should be lit by providing adequate lighting imitating vegetate light wave. The plant species proposed in the design should improve the quality of the air in the room and the aesthetic values of the interior of the public building. These plants clean the air, remove carbon dioxide and add more oxygen to the space, even at night. They assimilate toxins and remove them from the air, reducing stress and providing a more peaceful atmosphere. The proposed concept of the living wall combines the principles of sustainable design, recycling and up-cycling as well as the improvement of the biometeorological conditions of the interior of the building.

Streszczenie

Artykuł przedstawia pomysł ponownego wykorzystania odpadów opakowaniowych w konstrukcji i projektowaniu żywej ściany znajdującej się w budynku użyteczności publicznej. Przedstawiono pomysł wykorzystania odpadów opakowaniowych (butelek) jako materiału konstrukcyjnego i elementu dekoracyjnego do stworzenia żywej ściany. Materiały konstrukcyjne i projektowe proponowane w projekcie to głównie butelki szklane i plastikowe. Konstrukcja żywej ściany składa się z metalowej ramy wykonanej z perforowanych profili. Proponowane rośliny są dostosowane do warunków w danym pomieszczeniu. Instalacja obejmuje system nawadniania dla każdego poziomu zieleni. Zasugerowano doświetlenie zielonej ściany oświetleniem emitującym światło o długości fali właściwym do rozwoju wegetatywnego roślin. Gatunki roślin zaproponowane w projekcie powinny poprawić jakość powietrza w pomieszczeniu i walory estetyczne wnętrza budynku publicznego. Rośliny te oczyszczają powietrze, usuwają dwutlenek węgla i uwalniają tlen do przestrzeni, nawet w nocy. Absorbują toksyny i usuwają je z powietrza, redukując stres i zapewniając spokojniejszą atmosferę. Proponowana koncepcja żywej ściany łączy w sobie zasady zrównoważonego projektowania, recyklingu i upcyklingu, a także poprawy warunków biometeorologicznych we wnętrzu budynku.

Key words: living wall, packaging waste, recycling of packaging waste, green wall inside the building
Słowa kluczowe: zielona ściana, odpady opakowaniowe, recycling odpadów opakowaniowych, zielona ścian we wnętrzu budynku

1. Introduction

Urbanisation is a complex and diverse subject with multiple dimensions that include the economic, demographic, spatial, social, legal, and ecological aspects (Szymańska and Biegańska 2011). Uncontrolled urbanisation processes are one of the major, if not the most serious, social, economic, and environmental threat of our era (Kowalewski 2005). The effects of urbanisation are environmental transformation and pollution (Golem and Mustra 2013), which include, among others, air pollution, noise, water pollution, disturbances in water management, generating large amounts of waste, plant cover degradation, contamination and permanent development of land and soils, as well as microclimate changes that lead to the emergence of urban heat islands, transformation or even creation of a wholly new landscape.

As a result of the ongoing global urbanisation processes, most of the human population is living or will soon live in cities (Harasimowicz 2015). Thus, the concept of urban ecology including sustainable architecture (Wehle-Strzelecka and Korczyńska 2007) that improves the environmental, social and economic aspects of living in big cities will play an important role in shaping contemporary urban spaces.

Currently, urban architecture is affected by the so-called metropolization phenomenon, which is manifested in the construction of multi-storey buildings that have simple, clear and cold-looking forms. Today's agglomerations are becoming unfriendly to the community, because public spaces, whose tasks include satisfying the needs of residents and integrating people, depending on the function of the given place, do not foster human integration because of their industrial nature. This is why the idea of "green architecture" (which was available mainly in rich countries until recently) becomes vitally important (Kowalewski 2005), along with the development of green infrastructure (Puzdrakiewicz 2017). The latter includes creating living green roofs and vertical gardens, so-called green (living) walls (Szulczewska 2014).

Considering that roofs account for 20–25% of total urban area, green roofs have a great potential of influencing city environment. In modern cities, they may replace green areas that were lost to development and transportation (Cascone 2019). However, the potential of living walls is much higher than that of green roofs, because in city centres the degree of greening facades may be twice as high as the building area (Manso and Castro-Gomes 2015). The structures and construction technologies of green roofs vary. The main distinction is between intensive and extensive green roofs (Cascone 2019).The situation is similar with living walls. Here, the main classification distinguishes between green walls and green facades, where green facades are divided into direct (traditional green facades) and indirect (continuous guides, modular trellis), while living walls are divided into continuous (lightweight screens) and modular (trays, vessels, planter tiles, flexible bags) (Małuszyńska et al. 2014; Manso and Castro-Gomes 2015; Patro and Koper 2016; Madej 2018).

As a result of high pressure on developing every single patch of land in urban areas (particularly on street level), living walls and green roofs are becoming an alternative option of introducing greenery in developed city spaces (Manso and Castro-Gomes 2015). Additionally, introducing vegetation in form of green walls or roofs may foster the improvement of environmental conditions in strongly urbanised areas, including: increased biodiversity, stormwater management, quality of water from green roofs, improved air quality, lowered temperatures and mitigating the effects of urban heat island. Additionally, such walls or roofs provide thermal and acoustic protection of buildings and improve the aesthetic values and the living conditions of inhabitants (Manso and Castro-Gomes 2015; Puzdrakiewicz 2017; Pęczkowski et al. 2018; Burszta-Adamiak et al. 2019; Cascone 2019). On the scale of the building, they improve microclimate by functioning as an insulation layer in winter and in summer by offering shadow, an evaporative cooling effect, and absorbing solar radiation, increasing humidity and reducing the heating of hard surfaces, thus helping to lower energy consumption in the building (Manso and Castro-Gomes 2015; Cascone 2019).

Contemporary Europeans spend over 80% of time in various closed premises, without access to fresh air, often in adverse conditions in public buildings. The lack of proper ventilation in office premises is the main reason of reduced concentration and deteriorated well-being of employees, which motivates designers to take actions to improve air quality (Korta-Pepłowska et al. 2016). Vertical gardens may also be installed inside buildings. The microclimate that exists inside the buildings depends, to a large extent, on the pollution of the external environment and on the materials that were used during construction (Korta-Pepłowska et al. 2016). Additionally, most public utility buildings are equipped only with mechanical ventilation systems that provide the required amount of fresh air and remove the excessive heat, vapour and harmful volatile substances, which may result in increased temperature and reduced air humidity as well as deterioration in the well-being and health of the users (Pieczara 2016).

Installing green walls brings numerous benefits for users of these spaces. Vertical gardens planted inside buildings lower temperature and improve air quality as well as the microclimate (as they filtrate, ionise and humidify the air and capture dust). Moreover, they create a sound barrier that reduce the noise coming from outside and thus improving the mood and concentration of people working inside the building (Patro and Koper 2016).

Another problem that results from urbanisation is the growing amount of waste generated in urban areas, which requires increasing the expenditures on waste management (Wojtacha-Rychter and Białecka 2014; Harasimowicz 2015; Pai et al. 2014). One should remember that waste means any substance or object that the owner disposes of, intends to dispose of or is obliged to dispose of. Waste generated in households is referred to as municipal waste (Journal of Laws of 2019, item 701). On the other hand, packaging is a product manufactured from any relevant material that protects the given product from mechanical and biological damage during storage, transport, and distribution (Dejnaka 2011; Journal of Laws of 2019, item 542), which, after being withdrawn from use, becomes packaging waste (Journal of Laws of 2019, item 542). Both municipal and packaging waste may be subject to recycling or recovery, in the course of which it is reprocessed to manufacture products, materials or substances used for their original purpose or a different purpose (Journal of Laws of 2019, item 701). In recent years, the phenomenon of upcycling has become popular. The term refers to the process of recovery and processing of reusable materials with the aim to manufacture products of higher quality or different applications than the original product (Burzyński 2015).

In 2017, in Poland, 315 kg of municipal waste were generated per capita, whereas in the European Union it was 486 kg per capita (EUROSTAT 2019b). In 2016 in the EU 169.7 kg packaging waste was generated per capita, including 31.8 kg glass packaging per capita and 31.9 kg plastic packaging per capita, while in Poland it was respectively 148.6 kg, 31.0 kg, and 26.5 kg per capita. On the other hand, in the EU 114.0 kg packaging waste per capita was recycled, including 23.6 kg glass packaging per capita, and 13.6 kg plastic packaging per capita, while in Poland it was, respectively, 86.1 kg, 18.5 kg, and 12.5 kg per capita (EUROSTAT 2019a). The EU has reached the 55% level of recycling of packaging waste required by law (OJ L 365, 31.12.1994, OJ L 150, 14.6.2018), including 60% for glass and 22.5 for plastic waste. At the same time in Poland, the statutory level of recycling of packaging waste was achieved (58%), as well as of plastic waste (46.9%), although the required level for glass was not reached (obtained level 59.6%) (EUROSTAT 2019a).

The aim of the present study was to combine the idea of upcycling (a form of recycling) with the introduction of greenery to cities by creating living walls and by creating a concept design of a vertical garden with use of disposed glass packaging and elements of plastic packaging, in order to provide an alternative to traditional living walls. Additionally, the aim of the design of the living wall inside a public utility building was to improve the microclimatic conditions of the room (adverse ions and poor air circulation) as well as its aesthetic values.

2. Material and methodology

The concept of a living wall (vertical garden) presented in this paper was designed for a public interior located in the "G" building of the Faculty of Environmental Engineering and Geodesy of the Wrocław University of Environmental and Life Sciences (Fig. 1). The building was designed by Krystyna and Marian Barscy. The area is a corridor connecting the building of Melioration and the Geo-Info-Hydro Centre. It also serves as a recreational area for students. The communication paths (routes) cross in the central point of the hall. The windows, facing south, are surrounded by buildings that limit the incoming daylight. The room is lit by lighting tubes and halogen lamps, placed unevenly on the ceiling.

In order to determine the basic microclimatic parameters of the interior, measurements of air temperature, relative humidity and light intensity were taken with use of the Voltcraft DT 8820 multi-purpose meter (accuracy: lxmeter ±5% rdg, +10 dgt (in reference to colour temperature), higrometer ±5% (25°C, 35% ~95% RH), thermometer ±3% (rdg, +2°C at a resolution of 0.1). Measurements were taken four times, in November 2017, at 7:00 a.m., 1:00 p.m., and 7:00 p.m., at a distance of 1.0 m, from the designed wall, approximately 1.5 m above the floor. Light intensity was measured in the following variants: natural lighting, natural lighting plus full artificial lighting, natural lighting and only fluorescent tubes, natural lighting plus halogen lights. The location of the measurement point and the diagram of lighting are presented in Figure 2.

The concept design of the living wall was based on the assumption that the space will be used mainly by students and employees of the Wrocław University of Environmental and Life Sciences. The authors decided to use a modular construction system and to construct the living wall with use of packaging waste in form of disposed glass bottles (as pots) and plastic tapes obtained from PET bottles (fixing elements) placed on a steel rack. The authors of the design decided to

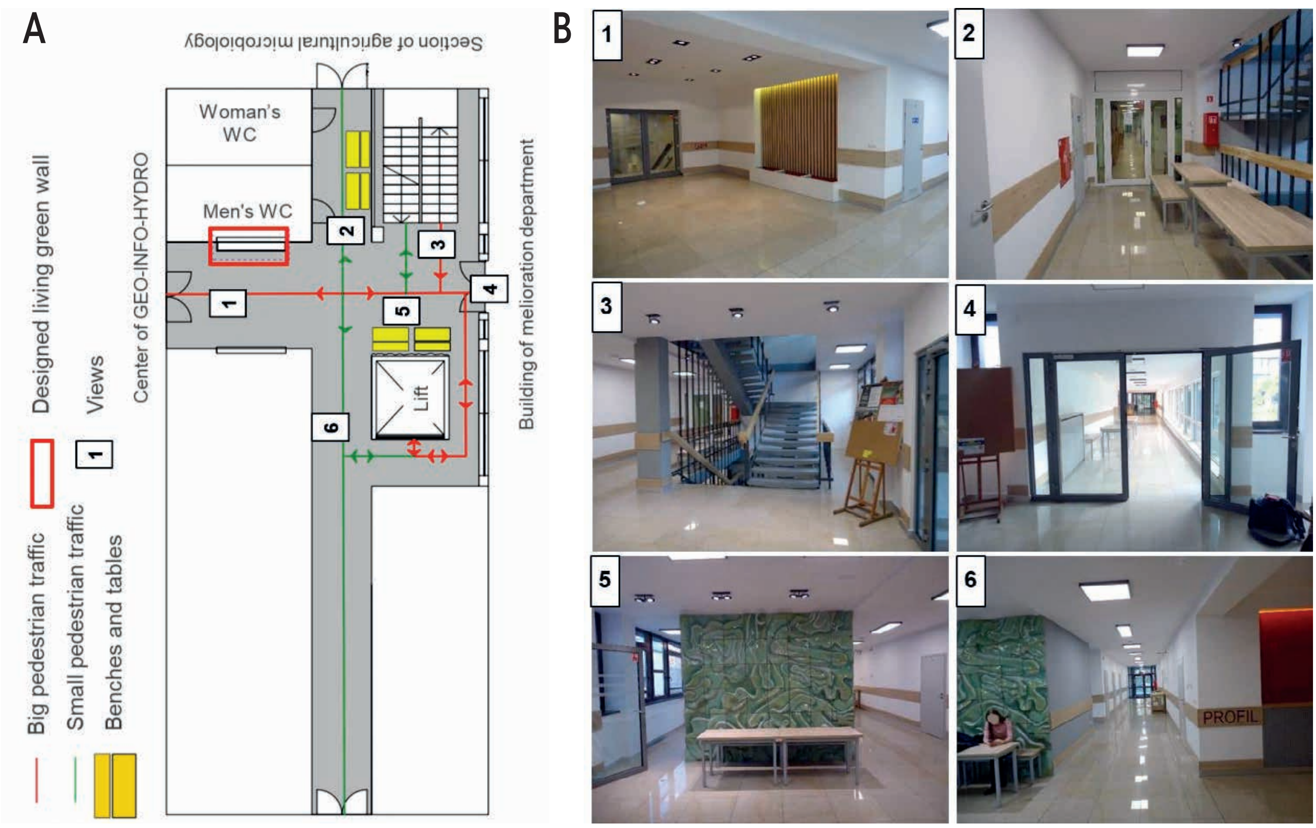

Fig. 1. Floor plan (A) and views (B) of the public interior for which the concept design was created (Source: Madej 2018, modified by B. Jawecki)

Ryc. 1. Schemat (A) i widoki (B) wnętrza publicznego będącego przedmiotem koncepcji (Źródło: Madej 2018, modyfikacja B. Jawecki)

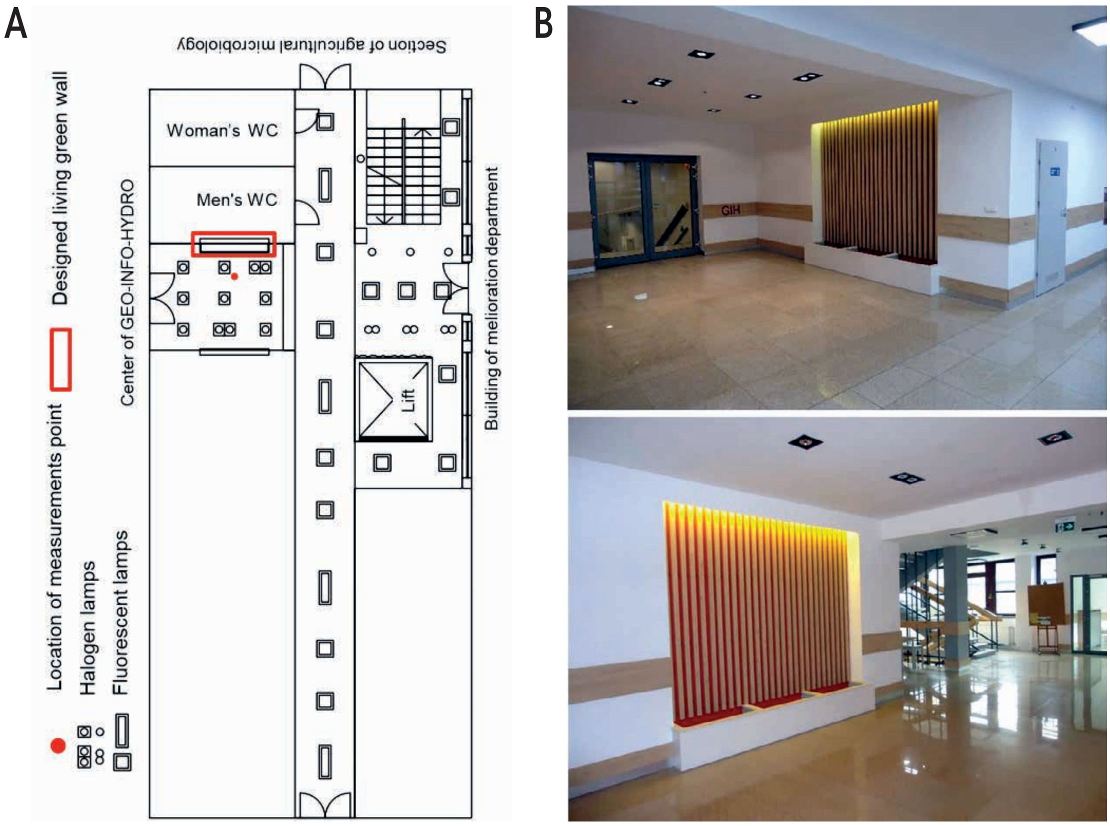

Fig. 2. Diagram of the placement of the lighting together with the location of the measurement site (A) and the view of the location of the designed living wall (B) (Source: Madej 2018, modified by B. Jawecki)

Ryc. 2. Schemat układu oświetlenia z lokalizacją punktu pomiarowego (A) oraz widok miejsca projektowanej żywej zielonej ściany (B) (Źródło: Madej 2018, modyfikacja B. Jawecki)

use species of potted plants that have good filtration capacity and that ionise the polluted air. The selected plants had to be adapted to survive in potentially difficult microclimatic conditions of a public interior. The authors also decided to connect the living wall to the water supply and sewage system being part of the building's infrastructure.

3. Results

The conducted air temperature measurements revealed (Fig. 3) that the average daily temperature (from 3 conducted measurements) was, on the average, 23.7°C: 23.1°C at 7.00 a.m., and 23.3°C at 1.00 p.m., and 24.6°C at 7.00 p.m. The results of relative humidity measurements demonstrated that the average daily relative air humidity (from 3 measurements taken) was, on the average, 40.5%: 43.3% at 7.00 a.m., 40.1% at 1.00 p.m., and 37.9% at 7.00 p.m. The obtained results demonstrate that both the air temperature and the relative air humidity meet the statutory requirements provided in binding Polish regulations (Journal of Laws of 2019, item 1065).

Light intensity tests revealed (Fig. 4) that, in the analysed period, the highest natural light intensity was noted at 1.00 p.m. although it did not exceed 6 lx. The maximum intensity of natural light together with fluorescent lamps did not exceed 25 lx and it was also noted at 1.00 p.m. The intensity of natural and halogen light did not exceed 295 lx, and the highest values were noted at 7.00 a.m. (2 times) and 1.00 p.m. (2 times). The highest light intensity was measured when both natural light and full artificial light was present. It reached even up to 300 lx (most often at 1.00 p.m.). It should be mentioned that in the analysed period the range of natural light intensity was below the values that enable the processes of photosynthesis and photoperiodism. Depending on the species, these value range from 27 lx even up to 5000 lx (Kurpaska 2008). Moreover,

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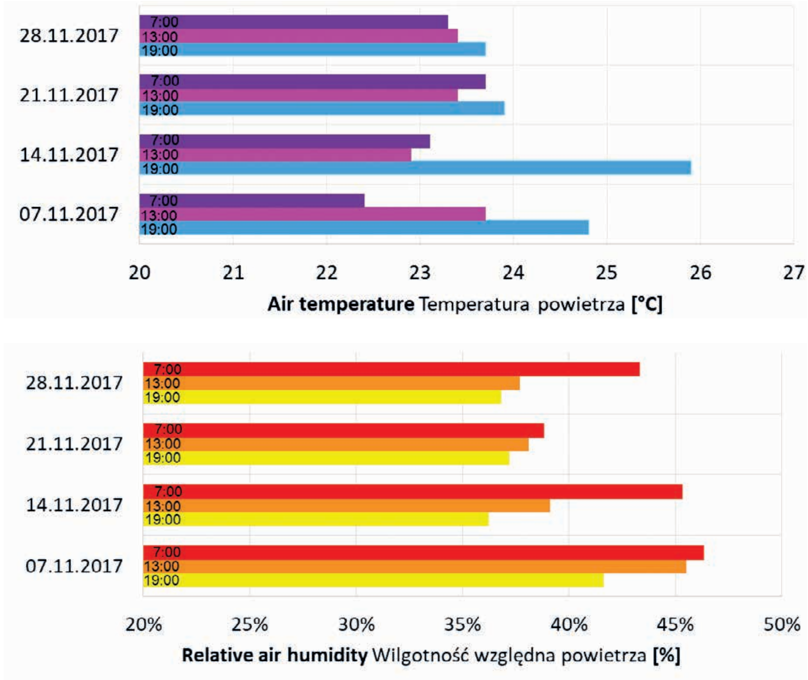

Fig. 3. Measurement results for selected microclimate elements in the analysed public interior (Source: Madej 2018)

Ryc. 3. Wyniki pomiarów wybranych czynników mikroklimatycznych w badanym wnętrzu publicznym (Źródło: Madej 2018)

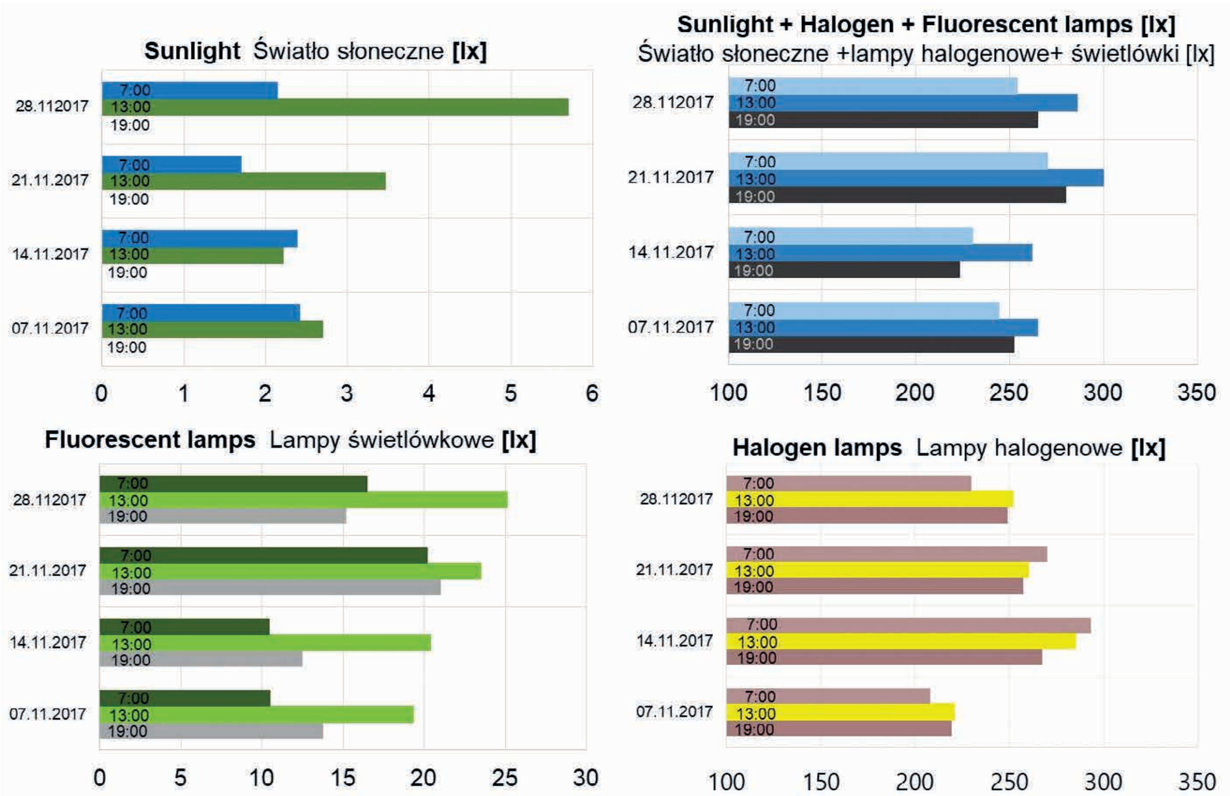

Fig. 4. Light intensity measurement results (Source: Madej 2018)

Ryc. 4. Wyniki pomiarów natężenia światła (Źródło: Madej 2018) additional lighting is recommended for plants without direct access to daylight or those located in places where light intensity does not reach 600–800 lx. In the winter season, such additional lighting should be provided for 12–14 hours per day (Nowak 1985). The additional lighting should ensure photosynthetically active irradiation, in the wavelength range of 370–740 nm. If mainly artificial light is used, the scope of wavelength is much narrower (Woźny 2012).

4. The concept of a living wall

The structure of the designed living wall is based on a modular scheme (Fig. 5). Elements of the rack supporting the structure are perforated steel profiles. The structural frame consists of angle brackets placed vertically and horizontally. Stabilising flat bars are designed to be placed on the top and bottom part of the rack. The elements are assembled with screws, nuts and plates (Madej 2018).

The glass bottles of various sizes that are proposed in the design to act as plant pots are prepared by cutting part of the bottle at an adequate angle (Fig. 6, 7). The edges should be polished after cutting. Pots should be placed on the rack, with the narrow section (the bottleneck) facing down. They are fastened by heat-shrinkable tapes obtained as a result of processing PET bottles (cutting PET bottles into tapes). The PET tape is wrapped around the glass pot in two places (Fig. 7). In order to stiffen the connection, the whole assembly should be evenly heated with a burner (Madej 2018).

The design includes an irrigation system (Fig. 6, 7) that crosses each tier of the ver-

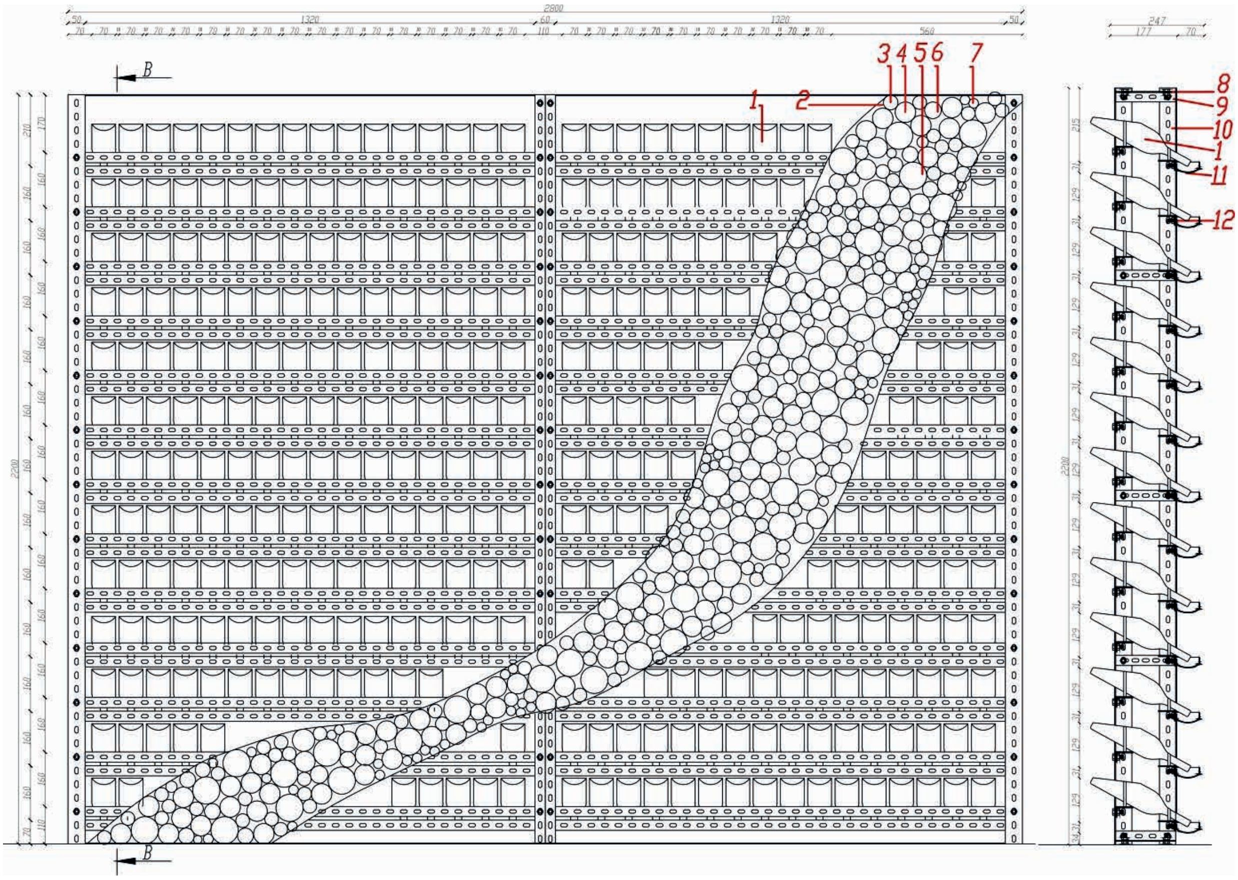

Fig. 5. Scheme of the structure of the rack, the set of pots made from glass bottles and the decorative element made from bottle bottoms. 1 – Flower Pot made of glass bottle 30×7×7; 2 – Milled OSB plate 12 mm; 3 – Bottoms of bottles ø40×20; 4 – Bottoms of bottles ø60×20; 5 – Bottoms of bottles ø80×20; 6 – Bottoms of bottles ø50×20; 7 – Bottoms of bottles ø30×20; 8 – Perforated flat 30×140; 9 – Perforated angle bracket 50×30×180; 10 – Perforated angle bracket 50×50×2200; 11 – Metal drainage gutter 70×2750; 12 – Screw fastening system (Source: Madej 2018, modified by B. Jawecki)

Ryc. 5. Schemat konstrukcji regału/stelażu, układu szklanych donic z butelek oraz elementu dekoracyjnego z szklanych denek z butelek. 1 – Doniczka wykonana ze szklanej butelki 30×7×7; 2 – Frezowana płyta OSB 12 mm; 3 – Dna butelek ø40×20; 4 – Dna butelek ø60×20; 5 – Dna butelek ø80×20; 6 – Dna butelek ø50×20; 7 – Dna butelek ø30×20; 8 – Perforowane płaskowniki 30×140; 9 – Perforowane kątowniki 50×30×180; 10 – Perforowane kątowniki 50×50×2200; 11 – Metalowa rynna drenażowa 70×2750; 12 – System mocowania śrubowego (Źródło: Madej 2018, modyfikacja B. Jawecki)

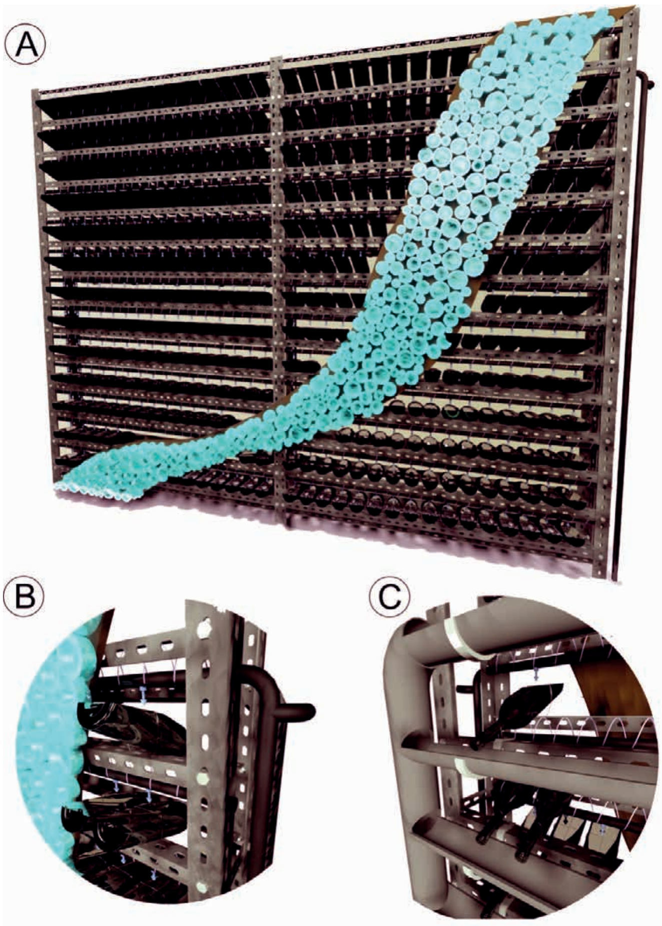

Fig. 6. Visualisation of the rack and the artwork of the living wall (A), of the drip irrigation system (B) and of the drainage system (C) (Source: Madej 2018, modified by B. Jawecki)

Ryc. 6. Wizualizacja regału/stelażu i kompozycji estetycznej zielonej żywej ściany (A), systemu nawodnienia kroplowego (B) oraz sytemu odwaniającego (C) (Źródło: Madej 2018, modyfikacja B. Jawecki)

tical garden. Irrigation pipes end with drippers that supply adequate water doses. The system is connected to a regulating electrovalve and collects water from the water supply network. Excess water is collected in the bottleneck and discharged to the sewage system by a set of drainage gutters (Madej 2018). An alternative solution may be a closed circulation system equipped with a water tank and a pump as well as irrigation control equipment, where excess water will be discharged back to the water tank by a set of drainage gutters. This will enable to save water and to distribute liquid fertilizers.

The decorative element of the living wall, which refers to the Aquarius – the symbol of the Faculty of Environmental Engineering and Geodesy, is a glass mosaic that shows a river flowing through greenery (Fig. 6). It is made from bottoms of glass bottles of various shapes and diameters, attached to an impregnated 12 mm thick OSB board. It is lit by a LED tape programmed so as to imitate the flow of water. The whole artwork is mounted on the rack with use of nuts and screws (Madej 2018).

The selection of plant species used in the arrangement (Fig. 8) is based on plants whose values and properties have a positive influence on the environment and with low

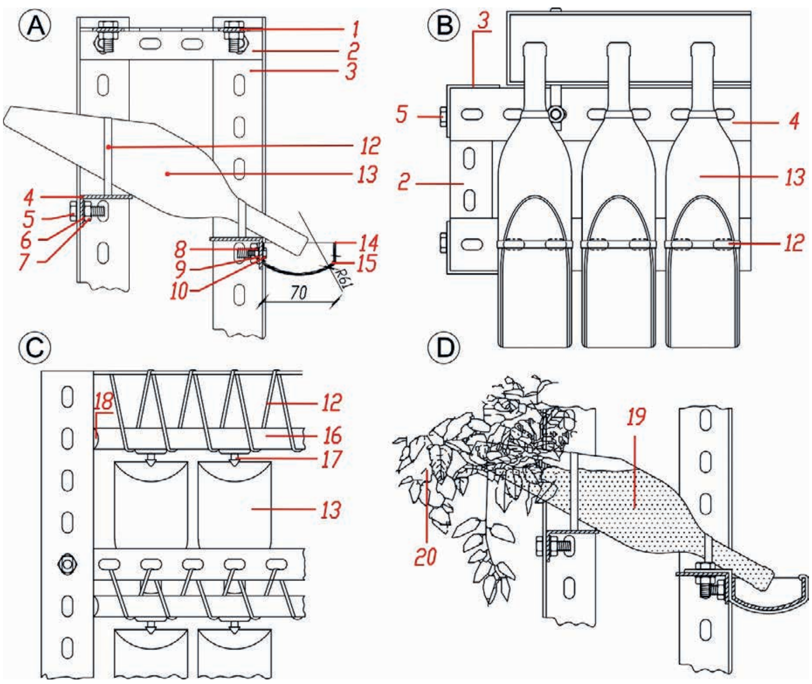

Fig. 7. Structural elements of the living wall. A – Structural detail of the rack, B – Detail / view from the top, C – Drip irrigation systems, D – Cross-section with plants. 1 – Perforated flat 30×140; 2 – Perforated angle bracket 50×30×180; 3 – Perforated angle bracket 50×30×2200; 4 – Perforated angle bracket 50×30×1400; 5 – Metal screw M12×35; 6 – Metal nut M12; 7 – Metal washer M12; 8 – Metal screw M6×35; 9 – Metal nut M6, 10 – Metal washer M6, 11 – Perforated flat 30×140; 12 – Flower pot made of bottle 30×7×7; 13 – Plastic (PET) tape; 14 – Metal drainage gutter 70×2750; 15 – Insulation coating; 16 – Irrigation pipe ø20, L280; 17 – Dripper; 18 – Plug; 19 – Substrate for plants; 20 – Plants (Source: Madej 2018, modified by B. Jawecki)

Ryc. 7. Schemat szczegółów konstrukcyjnych zielonej żywej ściany. A – Detal konstrukcyjny regału/stelaża, B – Szczegół / widok z góry, C – Systemy nawadniania kropelkowego, D – Przekrój przez doniczkę z rośliną. 1 – Perforowany płaskownik 30×140; 2 – Perforowany kątownik 50×30×180; 3 – Perforowany kątownik 50×30×2200; 4 – Perforowany kątownik 50×30×1400; 5 – Śruba metalowa M12×35; 6 – Metalowa nakrętka M12; 7 – Metalowa podkładka M12; 8 – Metalowa śruba M6×35; 9 – Metalowa nakrętka M6; 10 – Metalowa podkładka M6; 11 – Perforowany płaskownik 30×140; 12 – Doniczka z butelki 30×7×7; 13 – Taśma plastikowa (PET); 14 – Metalowa rynna drenażowa 70×2750; 15 – Powłoka izolacyjna; 16 – Rura irygacyjna ø20, L280; 17 – Kroplownik; 18 – Zatyczka; 19 – Podłoże do roślin; 20 – Rośliny (Źródło: Madej 2018, modyfikacja B. Jawecki)

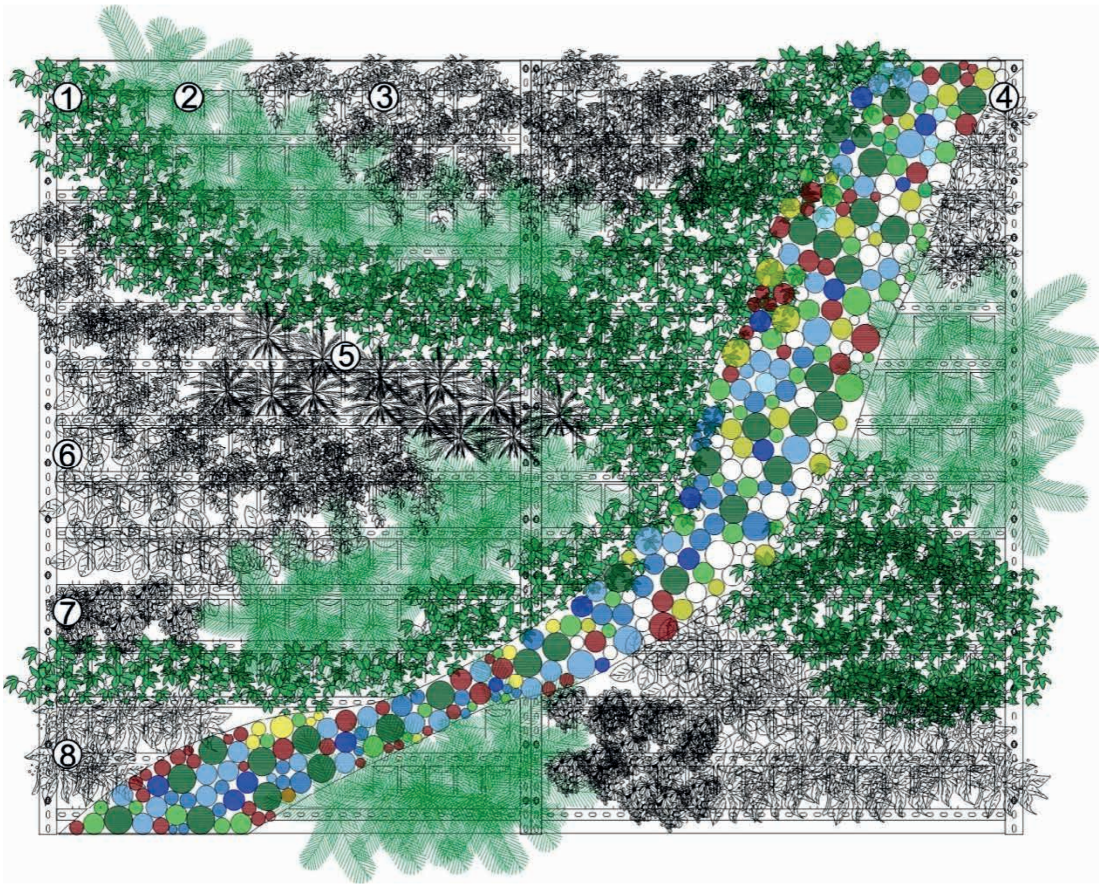

Fig. 8. Diagram of the placement of plants and of the artwork element. 1 – *Philodendron scandens* 'Oxycardium', 2 – *Nephrolepis exaltata* 'Bostoniensis nana', 3 – *Marantaa leuconeura* 'Erythroneura', 4 – *Cordyline terminalis* 'Red Edge', 5 – *Chlorophytum comosum*, 6 – *Epipremnum areum*, 7 – *Peperomia caperata*, 8 – *Spathiphyllum floribudum* (Source: Madej 2018, modified by B. Jawecki)

Ryc. 8. Schemat kompozycji układu roślin i elementu dekoracyjnego. 1 – *Philodendron scandens* 'Oxycardium', 2 – *Nephrolepis exaltata* 'Bostoniensis nana', 3 – *Marantaa leuconeura* 'Erythroneura', 4 – *Cordyline terminalis* 'Red Edge', 5 – *Chlorophytum comosum*, 6 – *Epipremnum areum*, 7 – *Peperomia caperata*, 8 – *Spathiphyllum floribudum* (Źródło: Madej 2018, modyfikacja B. Jawecki)

lighting requirements. They provide a natural air filter and improve the appearance of the interior. The proposed plants that have special toxin absorption capacity include golden pothos *Epipremnum areum* and snowflower *Spathiphyllum floribudum*. Additionally, in order to ensure that the wall would remain attractive throughout the year, varieties of unique leaf shapes and colours were proposed: The heartleaf philodendron *Philodendron scandens* 'Oxycardium', *Nephrolepis exaltata* 'Bostoniensis nana', Prayer plant *Marantaa leuconeura 'Erythroneura'*, Ti plant *Cordyline terminalis* 'Red Edge', Emerald Ripple peperomia *Peperomia caperata,* and, finally, the spider plant *Chlorophytum comosum.* In order to provide additional lighting for plants, the authors suggest installing a lighting system used for lighting green walls, with metal halogen lamps. The glass bottle pots should be filled with a substrate being a mixture of peat, perlite, dolomite and sand (Madej 2018), additionally fertilised with granulated fertilizer.

5. Summary and conclusions

The world of plants is the original, natural habitat of humans that has been necessary for us to survive since our species emerged on the planet. Oxygen generation, along with the absorption and neutralisation of carbon dioxide, are fundamental processes carried out by plants, without which humans would be unable to exist. In the era of growing urbanisation and covering the environment with concrete, vertical gardens in form of living walls may become an element that will mitigate the adverse anthropogenic impact on urban greenery. Another major problem of today's society is the generation of large

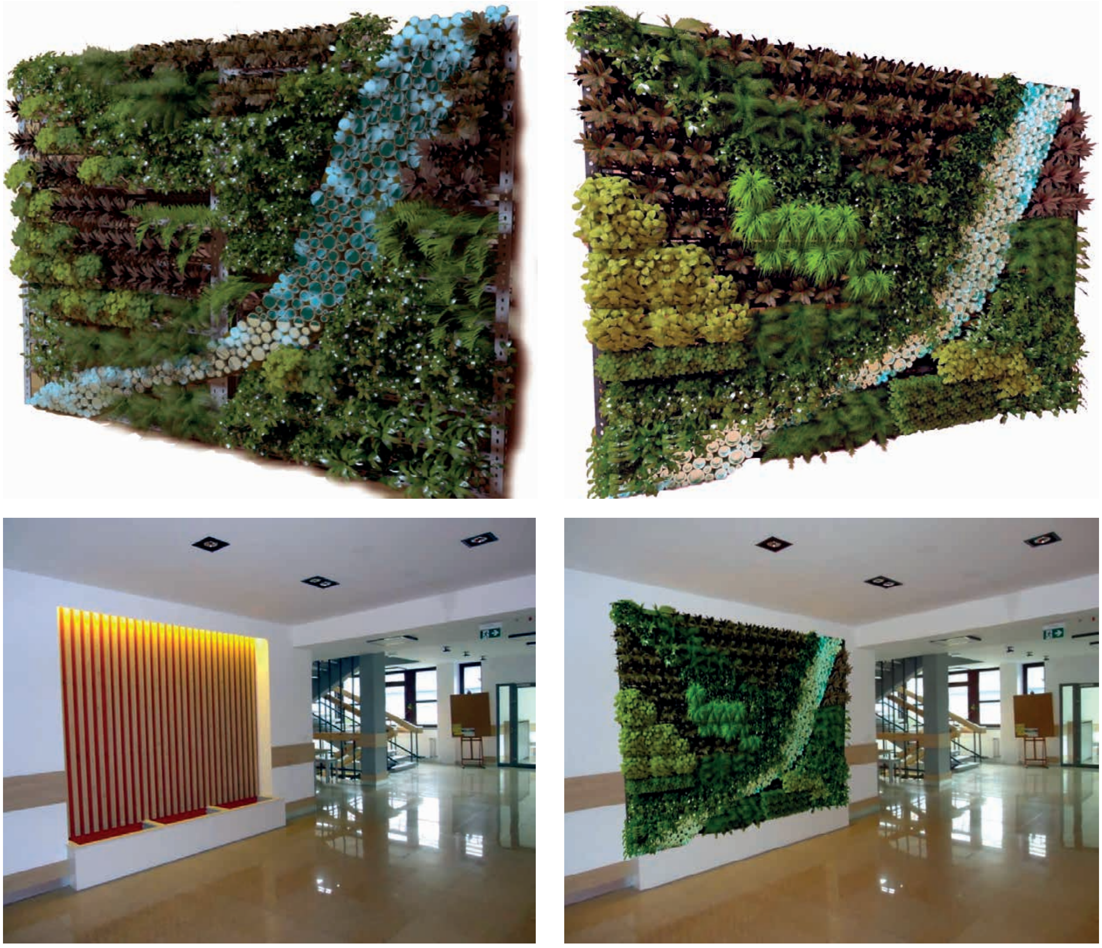

Fig. 9. Visualisation of the concept design of the green wall in a public interior (Source: Madej 2018, modified by B. Jawecki)

Ryc. 9. Wizualizacja koncepcji projektu zielonej ściany we wnętrzu publicznym (Źródło: Madej 2018, modyfikacja B. Jawecki)

amounts of waste. Part of it (e.g. glass and plastic packaging) is recyclable and could be reused successfully, but still too much of it is disposed on landfills or even waste dumps. In spite of the improved recovery and recycling of waste (mostly packaging waste) in Poland is improving and the increasing surface of green roofs and walls in urban areas, there is still much to be done.

The idea of recycling packaging waste by creating vertical gardens seems an interesting solution. The effects are illustrated by the presented idea of using disposed glass packaging in the concept design of a living wall in a public building interior, as a new structural model of vertical gardens (living walls). Applying such solution may reduce the costs of purchasing ready modular panels for vertical gardens. This concept is also environmentally friendly, because it promotes reusing materials, which are still considered as waste by part of the Polish society (in this case these are disposed glass and PET bottles). The concept was designed based on the idea of upcycling, i.e. reusing materials to create new objects of a higher value than the original materials.

The aim of the designed vertical garden in the public space of the buildings of the Faculty of Environmental Engineering and Geodesy of the Wrocław University of Environmental and Life Sciences is to clean and ionise the air, increase air humidity and produce oxygen. Apart from that, the proposed introduction of greenery to the interior of the building will have a positive influence on the health and well-being of users by reducing the concentration of certain allergens and microorganisms in the air. Not only does the installation provide a spectacular decorative element that improves the aesthetic values of the room (Fig. 9), but it also creates excellent conditions for efficient and creative work. Beautiful, fresh and luscious greenery creates a sense of peace, harmony and balance.

References

Harasimowicz A., 2015. Efekty aglomeracji – czynnik czy bariera rozwoju miast? Analiza wybranych aspektów w świetle literatury przedmiotu. Studia Miejskie (20), 23–34.

Burszta-Adamiak E., Stańczyk J., Łomotowski J., 2019. Hydrological performance of green roofs in the context of the meteorological factors during the 5-year monitoring period. Water and Environment Journal, 33 (1), 144–154. doi: 10.1111/wej.12385

Burzyński J., 2015. Upcykling. Najnowsze słownictwo polskie. Obserwatorium Językowe Uniwersytetu Warszawskiego. http://nowewyrazy.uw.edu.pl/haslo/upcykling.html [06.10.2019].

Cascone S., 2019. Green Roof Design: State of the Art on Technology and Materials. Sustainability (11), 3020; doi: 10.3390/su11113020

Dejnaka A., 2011. Opakowanie jako narzędzie wpływania na wybory konsumentów. Zeszyty Naukowe Wyższej Szkoły Bankowej we Wrocławiu, 23, 131–143.

Journal of Laws of 2019, item 1065. Obwieszczenie Ministra Inwestycji i Rozwoju z dnia 8 kwietnia 2019 r. w sprawie ogłoszenia jednolitego tekstu rozporządzenia Ministra Infrastruktury w sprawie warunków technicznych, jakim powinny odpowiadać budynki i ich usytuowanie.

Journal of Laws of 2019, item 542. Obwieszczenie Marszałka Sejmu Rzeczypospolitej Polskiej z dnia 22 lutego 2019 r. w sprawie ogłoszenia jednolitego tekstu ustawy o gospodarce opakowaniami i odpadami opakowaniowymi.

Journal of Laws of 2019, item 701. Obwieszczenie Marszałka Sejmu Rzeczypospolitej Polskiej z dnia 15 marca 2019 r. w sprawie ogłoszenia jednolitego tekstu ustawy o odpadach.

EUROSTAT 2019a: Packaging waste statistics. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Packaging_waste_statistics#Waste_generation_by_packaging_material [06.10.2019].

EUROSTAT 2019b. Municipal waste statistics. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Municipal_waste_statistics#Municipal_waste_treatment [06.10.2019].

Golem S., Mustra V., 2013. Decentralization of economic activities in the metropolitan area of Split. European Spatial Research and Policy, 20(2), 147–156, 147–156. https://doi.org/10.2478/esrp-2013–0016

Korta-Pepłowska M., Chmiel M.J., Frączek K., 2016. Zagrożenia mikrobiologiczne w środowisku pomieszczeń. Medycyna Środowiska, 19(2), 48–54.

Kowalewski A.T., 2005. Rozwój zrównoważony w procesach urbanizacji. Nauka, 1, 123–146.

Kurpaska S., 2008. Wpływ modyfikacji rozmieszczenia, źródeł światła na intensywność doświetlenia roślin w szklarni. Inżynieria Rolnicza, 10(108), 145–152.

Madej P., 2018. Wykorzystanie odpadów opakowaniowych w koncepcji projektowej zielonej ściany we wnętrzu publicznym. Praca inżynierska, Wydział Inżynierii Kształtowania Środowiska i Geodezji, kier. architektura krajobrazu. Maszynopis, s. 34, załączniki 13, opiekun dr inż. Bartosz Jawecki.

Małuszyńska I., Caballero-Frączkowski W.A., Małuszyński M.J., 2014. Zielone dachy i zielone ściany jako rozwiązania poprawiające zdrowie środowiskowe terenów miejskich. Inżynieria Ekologiczna (36), 40–52.

Manso M., Castro-Gomes J., 2015. Green wall systems: A review of their characteristics. Renewable and Sustainable Energy Reviews, (41), 863–871, https://doi.org/10.1016/j.rser.2014.07.203

Nowak C., 1985. Zieleń w zakładzie pracy, domu, osiedlu mieszkaniowym. Instytut Wydawniczy Związków Zawodowych, Warszawa.

OJ L 150, 14.6.2018. Directive (EU) 2018/852 of the European Parliament and of the Council of 30 May 2018 amending Directive 94/62/EC on packaging and packaging waste, 141–154.

OJ L 365, 31.12.1994. European Parliament and Council Directive 94/62/EC of 20 December 1994 on packaging and packaging waste, 10–23.

Pai R., Rodrigues L., Mathew A., Hebbar S., 2014. Impact of urbanization on municipal solid waste management: a system dynamics approach. International Journal of Renewable Energy and Environmental Engineering, 2(1), 31–37.

Parto M., Koper A., 2016. Ogrody wertykalne jako efektowny element zieleni w krajobrazie zurbanizowanym. Budowa i Architektura, 15(3), 145–154.

Pęczkowski G., Kowalczyk T., Szawernoga K., Orzepowski W., Żmuda R., Pokładek R., 2018. Hydrological Performance and Runoff Water Quality of Experimental Green Roofs. Water, 10, 1185; doi: 10.3390/w10091185

Pieczara J., 2016. Naturalne przewietrzanie i komfort termiczny w budynkach użyteczności publicznej. TEKA Komisji Architektury, Urbanistyki i Studiów Krajobrazowych (1), 29–39.

Puzdrakiewicz K., 2017. Zielona infrastruktura jako wielozadaniowe narzędzie zrównoważonego rozwoju. Studia Miejskie (27), 155–174, doi: 10.25167/sm2017.027.12

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Szulczewska B., 2014. W pułapkach zielonej infrastruktury [in:] A. Pancewicz (ed.) Zielona infrastruktura miasta, s. 9–29, Wydawnictwo Politechniki Śląskiej, Gliwice.

Szymańska D., Biegańska J., 2011. Fenomen urbanizacji i procesy z nim związane. Studia Miejskie (4), 13–38.

Wehle-Strzelecka S., Korczyńska A., 2007. Ochrona środowiska w kształtowaniu współczesnej przestrzeni miejskiej w aspekcie idei ekologii miasta (Environmental protection in the shaping of contemporary urban space from the point of view of urban ecology approach). Czasopismo Techniczne. Architektura, Wydawnictwo Politechniki Krakowskiej, (7), 55–64.

Wojtacha-Rychter K., Białecka B., 2014. Ocena potencjału produkcji i termicznej destrukcji paliw z odpadów w warunkach Śląska. Systemy Wspomagania w Inżynierii Produkcji, 3 (9), 237–248.

Woźny A., 2012. Zastosowanie światła w kontroli wzrostu i rozwoju roślin ozdobnych. Prace Instytutu Elektrotechniki (255), 225–234.

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Multi-storey car park structures as a potential carrier of greenery in cities

Budowle parkingów wielopoziomowych jako potencjalny nośnik zieleni w miastach

Abstract

The architecture of cubature car parks is usually simple, rectangular solids with a raw appearance, often accused of gloomy and overwhelming monotony of form and low aesthetic values.

However, it's easy to prevent these bad aesthetic effects by introducing greenery to their roofs and facades, which seems to be a perfect basis for the development of vegetation – mainly climbers and some perennials. Green creates a living cover that masks the interior of the object, as illustrated by examples of existing green parking lots. In addition to aesthetic values, it has a positive effect on improving the local microclimate, absorbs carbon dioxide, produces oxygen, reduces noise and provides shadow inside vehicles.

In the article several just constructed multi-storey car parks in Wrocław, which could be used as a base for the development of creepers and living green walls, were indicated. For each of them, the surface of the façade intended for greening was calculated and it was estimated how much oxygen it will produce and carbon dioxide absorb during the year. In addition, graphic visualizations were made showing the effects of this greening of the facades compared to their current state.

Streszczenie

Architektura kubaturowych parkingów samochodowych to najczęściej proste, prostopadłościenne bryły o surowym wyglądzie, nierzadko oskarżane o ponurą i przytłaczającą monotonię formy i niskie walory estetyczne.

Można jednak w prosty sposób zapobiec tym złym efektom estetycznym, wprowadzając zieleń na ich dachy i fasady, które doskonale nadają się na bazę do rozwoju roślinności – głównie pnączy oraz niektórych bylin. Zieleń tworzy żyjącą osłonę maskującą wnętrze obiektu, co ilustrują przykłady istniejących zazielenionych parkingów. Poza tym, oprócz walorów estetycznych, korzystnie wpływa na poprawę lokalnego mikroklimatu, absorbuje dwutlenek węgla, produkuje tlen, redukuje hałas oraz zapewnia cień stojącym wewnątrz pojazdom.

W artykule wskazano na kilka wybudowanych obiektów parkingów wielopoziomowych na terenie Wrocławia, które mogłyby się nadawać do jako baza do rozwoju pnączy i żyjących zielonych ścian. Dla każdego z nich obliczono powierzchnię fasady przeznaczonej pod zazielenienie oraz oszacowano, ile w ciągu roku wyprodukuje ona tlenu i pochłonie dwutlenku węgla. Ponadto wykonano wizualizacje graficzne przestawiające efekty tego zazielenienia fasad w porównaniu z ich stanem obecnym.

Key words: multi-storey car parks, greenery, city, façades, climber plants, green walls
Słowa kluczowe: parkingi wielopoziomowe, zieleń, miasto, fasady, rośliny pnące, zielone ściany

1. Introduction

Enclosed car parks are and will continue appearing increasingly in Poland's urban areas. Although they were anticipated in the 20th-century modernist planning concepts of new housing estates, the fact that they did not actually appear was due to the low demand for parking spaces[1] and the unaviability of such investments due to high construction costs.

The currently growing New Urbanism movement promotes the slogan: "Cities are for people, not for cars"[2]. In practice, this means that the introduction of traffic restrictions in inner-city areas and city centres creates the problem of a mass of cars being parked on the outskirts of these zones. And here, multi-storey car parks capable of accommodating several hundred or even several thousand cars become the answer. They can create the network of a "park and ride" parking system, particularly in suburban areas, or they can serve as strategic parking structures on the perimeters of strict city centres with restricted car traffic.

Such buildings have already been erected in several major Polish cities[3]. Depending on the city's urban planning policy, as well as its financial and technical capacity, these are multi-storey underground or above-ground parking structures. Above-ground car parks usually have a design that includes simple, rectangular shapes with a very raw appearance, and they are often accused of looking grim and overwhelmingly monotonous. Similarly to industrial buildings, this is due to the economics of construction costs and, above all, from the dominance of function and construction over the architectural form of these structures.

However, these poor aesthetics can easily be prevented by introducing greenery to the roofs and façades of parking structures. The inclusion of greenery as a permanent element contributing to the appearance of buildings follows the rapidly developing direction of green architecture (Wojciechowski, Vogt 2004). It is also an element protecting modern cities against one of the main threats to their natural environment and landscape aesthetics – the pervasive expansion of cars. This problem is highlighted by the creators of *The New Charter of Athens* who belong to the European Council of Town Planners. According to the assumptions of this charter, one of the main urban requirements of the 21st century will be protecting cities against pollution and the degradation of their natural assets so that they are able to maintain their usefulness (The New Charter of Athens 2003).

Simple vertical façades and flat roofs are perfect as a base for growing greenery – mainly vines and some perennials. Greenery climbing on special scaffolding, mesh, or even on the concrete walls of buildings, creates a living cover hiding their interior (Photo 1). In addition, it softens the raw, angular shapes, and by changing colours depending on the season, it provides a regular change of the colour of the walls. In addition, this peculiar symbiosis brings two-fold benefits to the city, because on the one hand, new parking structures imposed by transport needs are appearing, and on the other, the greenery masks their monotonous and functional design by creating living façades.

1.1. Aim of research

The aim of the study was to show the potential possibilities offered by the introduction of greenery on the curtain walls of parking structures, namely to indicate which of the selected objects in Wrocław could become a carrier of greenery and how this greenery could change the appearance of the facades of these objects. In addition, it was indicated what types of plants could be suitable for this and how they would be introduced to these façades. The summary of these studies was giving the size of the biologically active surface, obtained in this way, together with an estimate of the potential amount of carbon dioxide it absorbed and the oxygen it produced.

1 In the 1960–1980s, Poland had a conversion factor of one parking space per three new apartments (Dumnicki et al. 1979).

2 https://www.morizon.pl/blog/nowy-urbanizm-jak-ksztaltuje-wspolczesne-miasta/ [26.09.2019].

3 Multi-storey car parks built in whole or in part using municipal funds can be seen, for example, in Warsaw, Wrocław, Gdańsk, Poznań, Kraków, Gliwice, Rybnik, and Tychy (author's note).

1.2. Method of research

A comparative analysis of existing parking facilities in terms of their suitability for the selected role was adopted as the research method. The choice of how to introduce greenery on their façades, depends on the type of façade finishing material and the possibility of access to the soil in its vicinity, as well as on the technical conditions enabling the placement of structures supporting plants.

While choosing the facilities, their location in the city was guided (parking lots located in housing estates with high building density and high traffic density were chosen). The size of the façade surface and their finishing material were also important, as well as whether these objects no longer act as a greenery carrier (such as, for example, the Wroclavia shopping mall).

1.3. Advantages and disadvantages of placing creepers or a living wall on the façade[4]

In the case of greening the wall with creepers, the advantages of this technique are: natural irrigation with rainwater, moving vines away from the façade in the case of plants climbing on ropes or meshes, translucency of the façade between shoots, in the case of vine trees, changing colors in the annual cycle, attracting birds – increasing biodiversity (Marczyński 2016).

The disadvantages would be: making scaffolding[5] at the gaps in the facade and on the walls covered with smooth finishing materials, the use of usually one type of climber, the need for access to soil. Alternatively, you can plant vines in containers, but in the case of high-growing plants, it is definitely better to plant them directly in the ground, which also reduces the degree of exposure of the roots to freezing (Borowski and Latocha 2014).

The advantages of living walls are: no need for access to soil, large compositional possibilities due to various forms and colors of plants, species diversity, diverse selection of plants ensuring appropriate habitat conditions for various insect species.

The disadvantages of living walls would be: the need for scaffolding for plant panels along with substrate and plants, as well as waterproofing and drainage, execution of an electrically controlled plant irrigation system and optionally a specialist plant lighting system, energy supply and energy consumption (Kania et al. 2013).

The comparison of the capital expenditures related to the implementation and the cost of maintaining green façades made of vines and in the technology of living walls is much more favorable in the case of vines, as evidenced by their more frequent use on buildings, e.g. a parking lot in the Wroclavia shopping mall.

An important factor determining the choice of greening technique is, according to the author, the possibility of access to the soil along the façade of the parking lot, which allows planting vines in the soil next to the

Photo 1. Creepers climbing a steel mesh stretched on the concrete facade of the building. Multi-storey car park in the Wroclavia shopping gallery at Joannitów str. in Wrocław (Author's collection)

Fot. 1. Pnącza wspinające się po stalowej siatce rozciągniętej na betonowej fasadzie budynku. Parking wielopoziomowy w galerii handlowej Wroclavia przy ul. Joannitów we Wrocławiu (zbiory autora)

4 The author does not quote the price lists of individual structures and plant material needed to make green walls, because they quickly become outdated, but compares the advantages and disadvantages of both greening techniques (author's note).

5 The scaffolding structure should take into account the weight of the creeper, which depends on its species and age (on average 1–50 kg/m^2 of plant area) as well as wind load, dew, rain, snow and supports themselves (Marczyński 2016).

external wall. In the absence of such a possibility, it is proposed to hang containers for climbers on it. However, when there is no access to soil and containers with vines would disturb the aesthetics of the façade, a better but more expensive solution is to build a living wall based on its own construction.

2. Improved urban microclimate

In addition to clear aesthetic benefits, greenery has a very positive effect on the local microclimate around the parking structure – it cleans the air, reduces noise, decreases temperature, and provides the shade inside vehicles.

Air purification is the main and most-anticipated role of greenery in the city. Green walls are a significant contributor to this. Plants that form part of such green walls filter dust floating in the air and convert carbon dioxide to oxygen. One square meter of a green wall can annually absorb 2.3 kg of carbon dioxide from the air and produce 1.7 kg of oxygen. Green walls help reduce noise levels in a building's surroundings. It absorbs 41% more of noise than a normal façade, making the environment inside and outside of the building much quieter. Noise is reduced to 8 dB, i.e. it is halved. Green walls and vines reduce the air temperature in their environment. Plants take in sunlight, absorbing 50% and reflecting 30%. Climbers or external green walls help create a cooler and more humid climate, which reduces the urban heat island effect. Green walls make it possible to reduce the temperature in urban areas by 3°C [5].

Contrary to what one may expect, green walls help extend the life of a building's façade. It provides natural protection against the damaging effects of external atmospheric factors, such as sun, rain, wind and temperature fluctuations, slowing down the ageing process of façade materials. The roots of vines growing on façades also collect excess water that accumulates on the foundations of buildings, contributing to their drying (Borowski and Latocha 2014). From the point of view of car park users, another significant factor is the shade cast on the vehicles standing inside by living walls and climbers growing on the façades.

3. Advantages of climbers on façades

Creepers are one of the most effectively and attractively growing groups of plants used in public greenery. They are ideal for covering external building walls. They can grow high quickly, while densely hiding unsightly buildings and building structures (Photo 2). Their roots take up very little space, and the plants are able to cover very large façade surfaces with biologically active leaves. Vines are also very flexible, and thanks to their ability to attach to a variety of façade materials, they can adapt to all their shapes (Marczyński 2016).

Another advantage of climbers is their ability to absorb noise both by absorbing and scattering sound waves, which combined with the absorption and reduction of dust and gas concentrations in the air makes them ideal for creating green screens along streets and roads. In addition, their resistance to poor soil and harsh climatic conditions means that they are perfect for covering acoustic screens along transport routes, creating green walls. Considering the above advantages, they are also very well-suited for covering multi-storey car park structures.

On hot days, dense climbers can cast shade on parked vehicles inside semi-open parking lots. Vines play a very important role in cleaning the air and improving the urban microclimate. The ability to accumulate pollution, especially heavy metals, which is put out by daily traffic, is directly proportional to the surface area of all leaves. The multi-layered arrangement of leaves also increases the total biologically active surface area of the climber (Marczyński 2016).

Vines are able to very effectively blend in with the modern architecture. By climbing metal gratings, mesh and steel cables, they are ideal for visually creating modern buildings with glass, metal or concrete façades. They can also function as a decorative addition to façades that changes colour in autumn. An interesting example of this is the five-leaved ivy *(Parthenocissus quinquefolia*) growing on a creeper-like, plastic mesh that hides the steel structure of the ramp entrance cover above a shopping centre in Berlin (Photo 3).

4. Proposed solutions – research

The presented benefits of using vines and green walls for the urban environment and aesthetics of the urban landscape lead the author to propose their installation on the façades of several selected existing multi-storey car parks in Wrocław. Such greening of several multi-storey car parks in Wroclaw is possible after the installation of appropriate supporting structures on their façades.

For climbers, they can be metal ropes or mesh on frames, affixed directly to the façade, leaving about 10 cm of space from the wall for plants to wrap. In the case of objects with porous façades made of reinforced concrete or brick wall, plants, e.g. five-leaf vine (*Parthenocissus quinquefoila*) without auxiliary structures could be directly placed on them.

When it comes to green walls, the most commonly used structural solution are plant panels affixed in steel supporting structural modules anchored directly to the building façade (Kania et al. 2013).

Four multi-storey car park structures located in central Wrocław in the Stare Miasto (Old Town) and Szczepin estates were selected as useful for greening (Fig. 1). These are structures located along very busy communication routes and, in addition, in densely built-up areas that have very little greenery. Therefore, it seems reasonable to suggest using their façades in order to increase biologically active surfaces where they are located.

From the west of the city, these are the following structures:

- car park No. 1 at Słubicka Str. 18, at the shopping centre *TGG*;
- car park No. 2 at Zachodnia Str. 12, at the intersection with Litomska Str.;
- car park No. 3 at Braniborska Str. 14, at the shopping centre *Domar*;
- car park No. 4 at Kazimierza Wielkiego Str. 60, at the intersection with Łaciarska Str.

An analysis of these buildings was carried out in terms of the type of their building struc-

Photo 2. Concrete facade with creepers on a steel mesh. A local car park at Stanisława Herbsta Str. in Warsaw (Author's collection)

Fot. 2. Fasada betonowa z pnączami na stalowej siatce. Miejscowy parking przy ul. Stanisława Herbsty w Warszawie (zbiory autora)

Photo 3. Plastic coating with a vine creepers on the steel cover of the parking ramp. Eastgate shopping gallery at the Marzahn estate in Berlin (Author's collection)

Fot. 3. Powłoka z tworzywa sztucznego z pnączami winorośli na stalowej pokrywie rampy parkingowej. Galeria handlowa Eastgate na osiedlu Marzahn w Berlinie (zbiory autora)

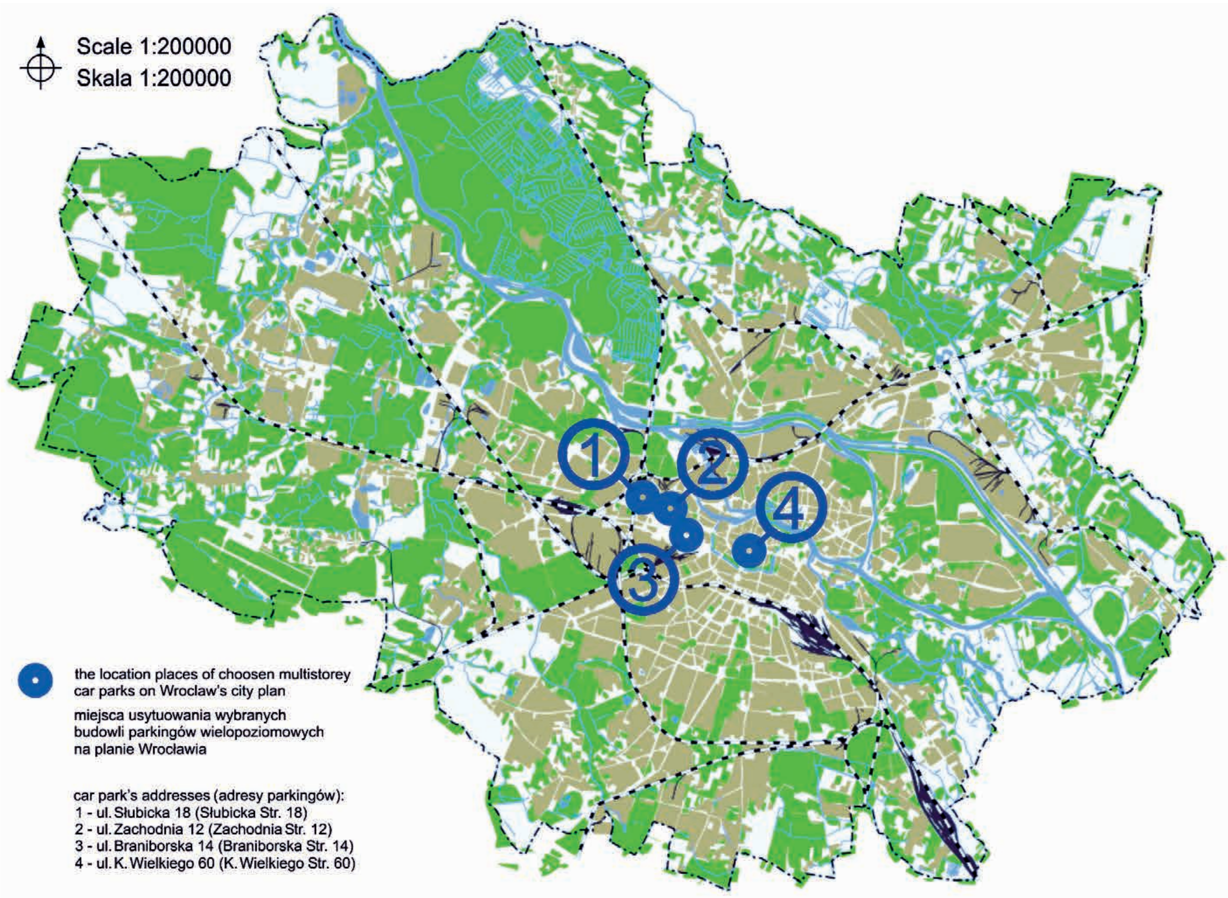

Fig. 1. Position of analyzed multi-storey car parks in Wrocław (Source: own study based on https://geoportal.wroclaw.pl/mapy/mapa_podst/)

Ryc. 1. Położenie analizowanych parkingów wielopoziomowych we Wrocławiu (Źródło: opracowanie własne na podstawie https://geoportal.wroclaw.pl/mapy/mapa_podst/)

ture, façade surface and their fragments best suited for greening, the type of greening, as well as the supporting structure and proposed examples of climbers and perennials. The results of these analyses are presented as a table (Table 1). The attached photos illustrate the current state and visual effect[6] after each of these structures was greened (Photos 4–7).

A proposal of introducing creepers on a supporting rope structure, on the example

[6] Visual effects were obtained by processing photos in Corel DRAW X6 (author's note).

Photo 4a. A car park at shopping gallery *TGG* at Słubicka Str. in Wrocław (car park No. 1) – current status (Author's collection)

Fot. 4a. Parking przy galerii handlowej TGG przy ul. Słubickiej we Wrocławiu (parking nr 1) – stan istniejący (zbiory autora)

Photo 4b. A car park at shopping gallery *TGG* at Słubicka Str. in Wrocław (car park No. 1) – proposal to introduce creepers and a green wall for the façade (Source: own study)

Fot. 4b. Parking przy galerii handlowej TGG przy ul. Słubickiej we Wrocławiu (parking nr 1) – propozycja wprowadzenia pnączy i zielonej ściany fasady (Źródło: opracowanie własne)

Table 1. Wall surfaces and methods of greening in selected parking lots (Source: own study)

Tabela 1. Powierzchnie ścian i sposoby zazieleniania na wybranych parkingach (Źródło: opracowanie własne)

Number of car park	Car park address	Construction type/ number of stories	Total surface of walls designated for greening	Type of greening and supporting structure	Proposed species: sunny side	Proposed species: shaded side
1.	Wrocław, Słubicka Str. 18	steel framework/ 3–4 stories	about 690 m²	creepers on steel strands (northern, western, southern wall)	• Thicket Creeper, False Virginia Creeper, Woodbine, or Grape Woodbine (*Parthenocissus inserta*) (*Celastrus orbiculatus*) alternatively	
				creepers sticking directly to the plastered wall (western wall)	• Virginia Creeper, Victoria Creeper, Five-leaved Ivy, or Five-finger Creeper – wall variety *(Parthenocissus quinquefoila* var. *murorum)* • Monkshood Vine *(Ampelopsis aconitifolia)* alternatively	
2.	Wrocław, Zachodnia Str. 12	reinforced concrete framework/ 3 stories	about 900 m²	creepers on steel strands (eastern, western wall)	• Thicket Creeper, False Virginia Creeper, Woodbine, or Grape Woodbine (*Parthenocissus inserta*) (*Celastrus orbiculatus*) alternatively	
				living wall (northern, southern wall)	group: • Azorella *(Azorella trifurcata)* • Eastern teaberry or checkerberry or boxberry *(Gaultheria procumbens)* • Oregano 'Aureum' *(Origanum vulgare 'Aureum')*	group: • Dwarf Periwinkle *(Vinca minor)* • Root Geranium *(Geranium macrorrhizum)* • Heuchera *(Heuchera 'Plum Pudding')*
3.	Wrocław, Braniborska Str. 14	reinforced concrete framework/ 4 stories	about 500 m²	climbers planted in containers located above the ground floor cornice, sticking directly to the reinforced concrete wall (northern, western wall)		• Virginia Creeper, Victoria Creeper, Five-leaved Ivy, or Five-finger Creeper – wall variety *(Parthenocissus quinquefoila* var. *murorum)* • Monkshood Vine *(Ampelopsis aconitifolia)* alternatively
				living wall (southern wall)	group: • Azorella *(Azorella trifurcata)* • Eastern teaberry or checkerberry or boxberry *(Gaultheria procumbens)* • Oregano 'Aureum' *(Origanum vulgare 'Aureum')*	
4.	Wrocław, Kazimierza Wielkiego Str. 60	reinforced concrete framework/ 6 stories	about 400 m²	living wall (southern, eastern, northern wall)	group: • Azorella *(Azorella trifurcata)* • Eastern teaberry or checkerberry or boxberry *(Gaultheria procumbens)* • Oregano 'Aureum' *(Origanum vulgare 'Aureum')*	group: • Dwarf Periwinkle *(Vinca minor)* • Root Geranium *(Geranium macrorrhizum)* • Heuchera *(Heuchera 'Plum Pudding')*

Photo 5a. A local car park at the junction of Litomska and Zachodnia Str. in Wrocław (car park No. 2) – current status (Author's collection)

Fot. 5a. Miejscowy parking przy skrzyżowaniu ulic Litomskiej i Zachodniej we Wrocławiu (parking nr 2) – stan istniejący (zbiory autora)

Photo 5b. A local car park at the junction of Litomska and Zachodnia Str. in Wrocław (car park No. 2) – proposal to introduce creepers and a green wall for the façade (Source: own study)

Fot. 5b. Miejscowy parking przy skrzyżowaniu ulic Litomskiej i Zachodniej we Wrocławiu (parking nr 2) – propozycja wprowadzenia pnączy i zielonej ściany na elewację (Źródło: opracowanie własne)

Photo 6a. A car park at shopping gallery *Domar* at Braniborska Str. in Wrocław (car park No. 3) – current status (Author's collection)

Fot. 6a. Parking przy galerii handlowej Domar przy ul. Braniborskiej we Wrocławiu (parking nr 3) – stan istniejący (zbiory autora)

Photo 6b. A car park at shopping gallery *Domar* at Braniborska Str. in Wrocław (car park No. 3) – proposal to introduce creepers for the façade (Source: own study)

Fot. 6b. Parking przy galerii handlowej Domar przy ul. Braniborskiej we Wrocławiu (parking nr 3) – propozycja wprowadzenia pnączy do fasady (Źródło: opracowanie własne)

Photo 7a. A city car park at the junction of Kazimierza Wielkiego and Łaciarska Str. in Wrocław (car park No. 4) – current status (Author's collection)

Fot. 7a. Parking miejski u zbiegu ulic Kazimierza Wielkiego i Łaciarskiej we Wrocławiu (parking nr 4) – stan istniejący (zbiory autora)

Photo 7b. A city car park at the junction of Kazimierza Wielkiego and Łaciarska Str. in Wrocław (car park No. 4) – proposal to introduce a green wall for the façade (Source: own study)

Fot. 7b. Parking miejski u zbiegu ulic Kazimierza Wielkiego i Łaciarskiej we Wrocławiu (parking nr 4) – propozycja wprowadzenia zielonej ściany fasady (Źródło: opracowanie własne)

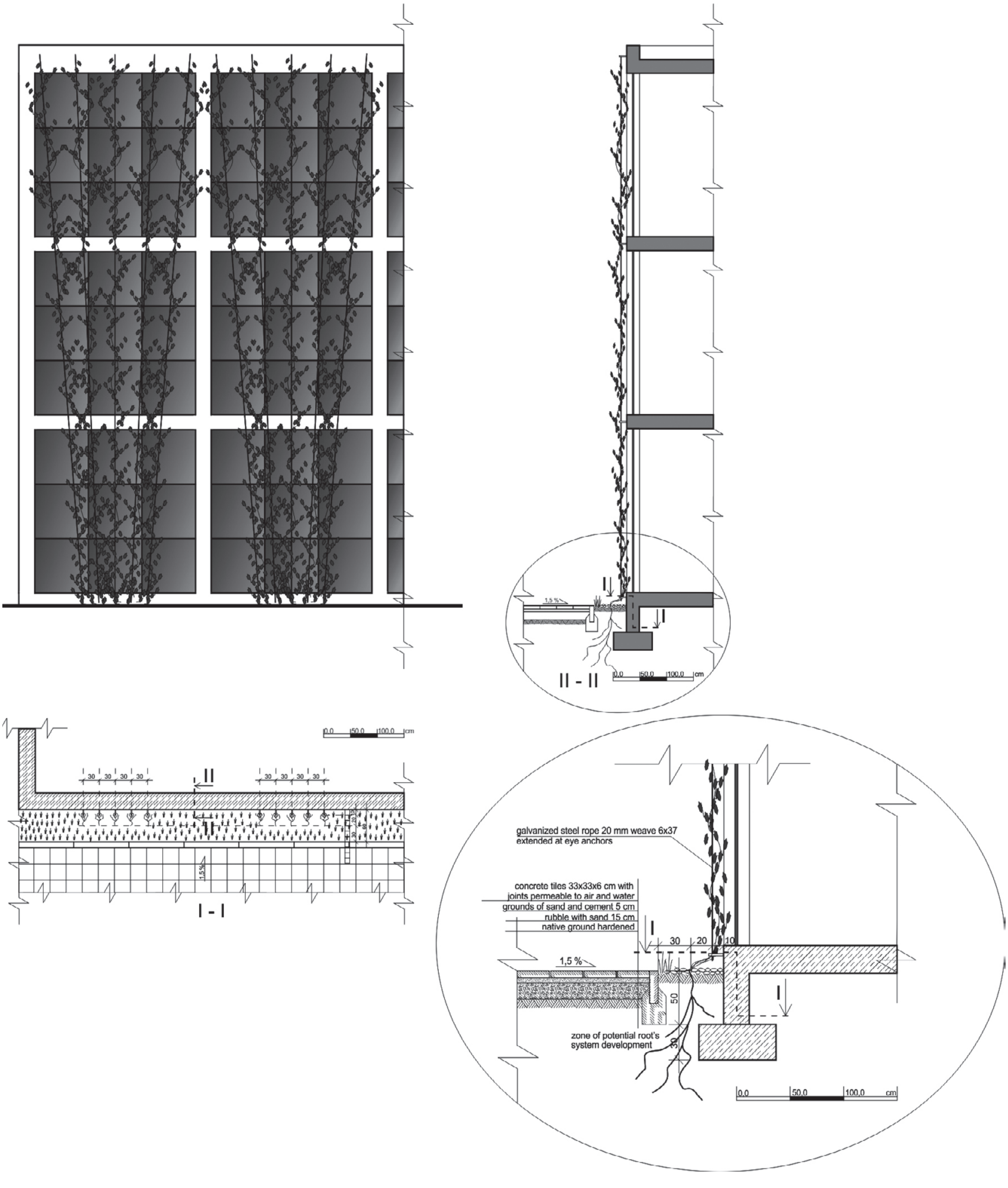

Fig. 2. A proposal to introduce creepers on the supporting structure on the example of a car park at Zachodnia Str. 12 (Source: own study)

Ryc. 2. Propozycja wprowadzenia pnączy na konstrukcji nośnej na przykładzie parkingu przy ul. Zachodniej 12 (Źródło: opracowanie własne) of a car park at Zachodnia Str. 12 in Wroclaw, is shown in Figure 2. The species proposed by the author for use in this case are the scrub creeper (*Parthenocissus inserta*) or Asiatic bittersweet (*Celastrus orbiculatus*). Creepers would be planted 30 cm from the facade in a green's belt about 60 cm of wide at intervals of 30 cm. Due to the small area of permeable soil, systematic fertilization should be introduced there once a year.

Calculating the surface of green walls suitable for greening for each of these objects, one could try to estimate what would be the number of square meters of green walls. Based on the conversion factors quoted in point 2, saying that 1 m^2 of green wall can produce 1.7 kg of oxygen per year and absorb 2.3 kg of carbon dioxide, we can count how much potentially the green walls of each parking lot could produce oxygen and absorb carbon dioxide.

The results of these calculations are presented in Table 2.

The total surface area of the green walls of all four parking structures is approximately 2,490 m^2 of additional biologically active surfaces in the city centre. Based on the conversion factors cites in item 2, this area can produce 4233 kg of oxygen during a year and absorb 5727 kg of carbon dioxide at the same time.

Covering scaffolding by climbers on the facade can take several years, depending on the type of climber and the size of the support (Baumann 1991). Taking into account the annual growth of grapevine, 1.5–2.5 m/year (Borowski and Latocha 2014), it can be assumed that the walls of the car park at Zachodnia Str. 12, whose height reaches about 9 m as well as the northern concrete facade of the car park at Braniborska str. 14, measuring 8 to 10 m in height, will green completely after about 5 years.

5. Summary

Placing the proposed vines and green living walls on the façades not only improved the aesthetics of the car parks in question but should give measurable environmental effects.

Adding up the green walls of all four parking lots, we can get about 2,490 m^2 of additional biologically active space in the city center. This area can annually produce 4,233 kg of oxygen while absorbing 5,727 kg of carbon dioxide and what is important, this can take place in places that are deficient in greenery and exposed to everyday dust and exhaust pollution.

In summary, it can be stated that the greenery growing on multi-storey or field car parks mitigates their negative effects both in terms of ecological harm and interference in the

Table 2. Wall surfaces and potential O_2 production and CO_2 absorption in selected parking lots (Source: own study)

Tabela 2. Powierzchnie ścian oraz potencjalna produkcja O_2 i absorpcja CO_2 na wybranych parkingach (Źródło: opracowanie własne)

Number of car park	Car park address	Total surface of greenable walls	Wall's exposure	O_2 production / year	CO_2 absorption / year
1.	Wrocław, Słubicka Str. 18	about 690 m^2	southern, western, northern	1173 kg	1587 kg
2.	Wrocław, Zachodnia Str. 12	about 900 m^2	western, southern, eastern, northern	1530 kg	2070 kg
3.	Wrocław, Braniborska Str. 14	about 500 m^2	northern, western, southern	850 kg	1150 kg
4.	Wrocław, Kazimierza Wielkiego Str. 60	about 400 m^2	southern, eastern, northern	680 kg	920 kg
	Total	2490 m^2	–	4233 kg	5727 kg

aesthetics of the urban landscape. Improving the aesthetic value of city parking structures is a great opportunity for landscape architects to display their creative skills; their role should be to design the car parks themselves as well as the surrounding spaces so that they are harmoniously blended into the landscape, positively contribute to its aesthetics, and constitute a colourful touch (Burdziński 2012).

References

Baumann R., 1991. Domy w zieleni. Wydawnictwo Arkady, Warszawa.

Borowski J., Latocha P., 2014. Zastosowanie roślin pnących i okrywowych w architekturze krajobrazu. Wydawnictwo SGGW, Warszawa.

Burdziński J., 2012. Odnowa wizerunku terenów parkingowych. Architektura Krajobrazu, nr 3, 91–99.

Dumnicki J., Kreczmer J., Remisz S., 1979. Parkingi w miastach. Wydawnictwa Komunikacji i Łączności, Warszawa.

Korzyści jakie daje zielona ściana. https://www.sempergreen.com/pl/rozwiazania/zielone-sciany/korzysci-jakie-daja-zielone-sciany [26.09.2019].

Marczyński S., 2016. Pnącza w zieleni miejskiej i przy drogach. Clematis Źródło Dobrych Pnączy, Pruszków.

Nowa Karta Ateńska 2003. Wizja miast XXI wieku. Towarzystwo Urbanistów Polskich (red.), Lizbona. http://www.zabytki-tonz.pl/pliki/karta atenska 2003_pl.pdf [25.09.2019].

Nowy Urbanizm – czym jest i jak kształtuje współczesne miasta? https://www.morizon.pl/blog/nowy-urbanizm-jak-ksztaltuje-wspolczesne--miasta/ [26.09.2019].

The New Charter of Athens 2003. Vision for Cities in the 21st century. The European Council of Town Planners (ECTP), http://www.itc.cnr.it/ba/re/Documenti/The New Charter of Athens 2003.htm [18.02.2020].

Wojciechowski N., Vogt B., 2004. Podstawy i przykłady rozwiązań w „green architecture". Czasopismo Techniczne. Środowisko, r. 101, z. 9-Ś, 127–133.

Kania A., Mioduszewska M., Płonka P., Rabiński J.A., Skarżyński D., Walter E., Weber-Siwirska M., 2013. Zasady projektowania i wykonywania zielonych dachów i żyjących ścian. Poradnik dla gmin. Stowarzyszenie Gmin Polska Sieć „Energie Cites", Kraków.

Summary

Urban space is undergoing increasingly noticeable transformations that result not only from the development of town planning, but are also caused by climate changes that force us to transform our approach to designing whole cities or individual buildings. The expectations of residents of such transforming towns focus on solutions that are not only trendy, but healthy and environmentally friendly. In this context, the role of green infrastructure in cities is becoming increasingly important. Its main aim is to improve the quality of life in urban areas by introducing high quality ecosystem services offered by elements of nature. Green roofs and green walls are a perfect element of this mission. A particularly important advantage of these solutions is their versatility. Establishing green roofs and vertical gardens improves thermal insulation and stability of the given structure, influences the microclimate and air cleansing, enhances water retention, and, finally, increases biodiversity. However, in order to take green infrastructure into account in spatial planning of modern cities, legislation on the European Commission level is required, as well as introducing national and local legal regulations.

The first part of the monograph discussed formal and legal aspects of the issue. The authors point out that legislation should be aimed at the popularisation of green infrastructure in cities, which will be beneficial both for the environment and for the inhabitants. The second part offers the reader plenty of inspiration for introducing greenery to buildings. The presented examples illustrate a broad spectrum of possibilities to apply green roofs and green walls on such public utility buildings as shopping malls, skyscrapers or multi-storey car parks, as well as in the interiors, for example in workplaces. The examples discussed in the publication refer not only to completed investments, but also to developed concept designs of green structures. The authors of individual chapters share their observations based on experiences from Poland and abroad, including from China, Ukraine, Switzerland, Germany, and Spain. Apart from traditional construction solutions, the publication presents an interesting method of using waste to provide additional aesthetic values of green roofs and green walls. To improve the understanding of the functionalities of green roofs, further chapters present the results of research on the condition of selected plant species that constitute an integral part of such green structures.

The monograph that you are reading, presents a multitude of aspects of the topic of green roofs and walls. It may support adaptation activities and foster more conscious formation of green infrastructure strategies in cities. In constantly spreading metropoles, where developed areas consume more and more biologically active areas, the development of green structures on buildings may be a path worth choosing in order to achieve natural balance in urban areas

Key words: green roofs, green walls, urban area, green infrastructure, town planning, greenery, good practices

Streszczenie

Przestrzeń miast ulega coraz bardziej widocznym przekształceniom wynikającym nie tylko z postępu urbanizacyjnego, ale także ze zmian klimatu, które wymuszają transformację podejścia do planowania miast czy projektowania budynków. W przeobrażających się miastach oczekiwania mieszkańców koncentrują się na rozwiązaniach nie tyle modnych, co zdrowych i ekologicznych. W tym kontekście rola zielonej infrastruktury w miastach nabiera większego znaczenia. Jej głównym celem jest podniesienie jakości życia na obszarach zurbanizowanych dzięki wysokiej jakości usług ekosystemowych oferowanych przez elementy przyrodnicze. Doskonale wpisują się w tę misję zielone dachy i roślinne ściany. Szczególnie istotną kwestią przemawiającą na korzyść tego typu rozwiązań jest ich wielofunkcyjność. Zakładanie zielonych dachów oraz ogrodów wertykalnych poprawia termoizolacyjność i trwałość konstrukcji, wpływa na mikroklimat i oczyszczanie powietrza, wzmacnia retencję wody oraz wzbogaca różnorodność biologiczną. Jednak uwzględnienie zielonej infrastruktury w planowaniu przestrzennym współczesnych miast wymaga zapisów legislacyjnych na poziomie Komisji Europejskiej, jak też uregulowań prawnych na szczeblu krajowym i lokalnym.

W pierwszej części monografii zostały omówione zagadnienia formalne i prawne. Autorzy zgodnie wskazują, że ustawodawstwo powinno służyć upowszechnieniu zielonej infrastruktury w miastach z korzyścią zarówno dla środowiska, jak i mieszkańców. W drugiej części monografii czytelnik znajdzie szereg inspiracji do wprowadzania zieleni na budynki. Prezentowane przykłady pokazują spektrum możliwości stosowania zielonych dachów i roślinnych ścian na budynkach użyteczności publicznej takich jak centra handlowe, drapacze chmur czy parkingi wielopoziomowe oraz we wnętrzach pomieszczeń, w tym w miejscach pracy. Omówione przykłady odnoszą się nie tylko do zrealizowanych inwestycji, lecz także do opracowanych koncepcji zielonych konstrukcji. Autorzy poszczególnych rozdziałów dzielą się swoimi spostrzeżeniami na bazie doświadczeń polskich oraz zagranicznych, w tym chińskich, ukraińskich, szwajcarskich, hiszpańskich i niemieckich. Poza tradycyjnymi rozwiązaniami konstrukcyjnymi przedstawiono interesujący sposób wykorzystania odpadów do zapewnienia dodatkowych walorów estetycznych na zielonych dachach i roślinnych ścianach. W kolejnych rozdziałach, w celu lepszego zrozumienia funkcjonalności zielonych dachów, zaprezentowano wyniki badań kondycji wybranych gatunków roślin, które są integralną częścią zielonych konstrukcji.

Monografia znajdująca się w Państwa rękach prezentuje temat zielonych dachów i roślinnych ścian na wielu płaszczyznach, co może być wsparciem działań adaptacyjnych oraz świadomego kształtowania strategii zielonej infrastruktury w miastach. W przypadku stale rozrastających się metropolii, których zabudowa pochłania kolejne fragmenty terenów biologicznie czynnych, rozwój zielonych konstrukcji na budynkach może być wartą wybrania drogą do osiągnięcia równowagi przyrodniczej na obszarach zurbanizowanych

Słowa kluczowe: zielone dachy, zielone ściany, teren zurbanizowany, zielona infrastruktura, planowanie miasta, zieleń, dobre praktyki

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